SLOWING DOWN OF SUPERTANKERS BY USE OF SEMI-TANDEM KEEL MOUNTED PLATES

Paul Peter Daulerio

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by

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B.S., United States Naval Academy

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TECHNOLOGY

June, 1970

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May 21, 1970

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Mechanical Engineering Department Reader

Accepted by ______________________________
Chairman, Departmental Committee on Graduate Students

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Submitted to the Department of Naval Architecture and Marine Engineering and the Department of Mechanical Engineering on May 21, 1970 in partial fulfillment of the requirements for the degrees of Master of Science in Naval Architecture and Marine Engineering and Master of Science in Mechanical Engineering.

A B S T R A C T

This thesis investigates the increased drag of a supertanker through the addition of flat plates mounted on the keel normal to the flow.

Several arrays of these plates are analyzed for their drag producing ability and the results enumerated in tabular and graphical form. The arrays are compared one to another to determine the optimum or near optimum solution. In conjunction with the above, the percent reduction in head reach of a supertanker with various arrays affixed to the keel as opposed to a no-brake system is calculated and tabularized.

Thesis Supervisor: J. Nicholas Newman

Title: Associate Professor of Naval Architecture

ACKNOWLEDGEMENTS

Throughout the course of my thesis work, I have been extremely fortunate to have been associated with many talented and helpful people. An enormus thank you goes to Professor Newman and Professor Jaffrin for their constructive criticism, encouragement and undying patience during the experimentation and preparation of this thesis. Further, a special thanks goes to Professor Chryssostomidis for his uncanny ability to uncover obscure references and his sustained willingness to help.

Finally, I wish to thank my wife, Donna, for her infinite secretarial skills used in the preparation of this manuscript.

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INTRODUCTION

Spurred on by the incentive of larger and larger revenues obtained from greater and greater cargo carrying capabilities, the merchant marine industry has gone to ships with a full load displacement upwards of 100,000 tons. With the evolution of these enormus tankers, which are better known as supertankers, came the associated problems facing most existing ships of comparable size. One of the most formidable is the slowing down or deceleration of these ships from their normal service speed of 16 knots.

The factor that must be overcome in stopping a supertanker is the associated kinetic energy ($1/2\ M\ V^2$).[8] When one stops to think that the value of M is extremely large for supertankers, it is not difficult to appreciate the force necessary to overcome the kinetic energy attained by a supertanker even at low speeds. If nothing else, we have at least an intuitive feeling based on the above that the stopping times and distances of supertankers will be large. In practice this is just the case.

The problem becomes most acute when the ship is operating under low visibility conditions or entering a port. In either situation, the dangers of collision are paramount. Based on existing Rules of the Road, the supertankers face a situation in extremus by their very existence

on the high seas under low visibility conditions due to the large head reach involved; i.e., distance traveled by the ship during deceleration.

The forces available to oppose the motion of a supertanker are hull resistance and propeller thrust. Model tests have been conducted to determine the effect of the propeller in decelerating a ship.[14] The head reach has been measured under the conditions of (1) "natural" deceleration, or that caused by only hull resistance with the propeller free turning, and (2) crash-back deceleration or that caused by the propeller turning in the full astern thrust mode. In both cases, the ship traveled 40 percent of its total head reach during the time it took to reduce the speed to one-third its original value and 80 percent of its total head reach during the reduction to one-half of its original speed. Since the astern thrust does not reach its maximum value until the ship has traveled 80 percent of its total head reach, the effectiveness of the propeller is nominal at high speeds, the decelerating force being almost entirely derived from the hull resistance. The propeller becomes the dominating factor only in the speed range of one to six knots. Therefore, from the above, it is evident that increasing the installed machinery power is not the answer to the stopping problem.[8]

There are two obvious ways to help reduce the severity of the situation. One is to decrease the initial speed from which the deceleration must take place. However, as

with most things in today's society, time is money; hence, a rapid transit time for a supertanker is imperative. Thus, this solution is not looked upon favorably. Another partial remedy would be to reduce the time between the order from the bridge to reverse the engines and the actual reversing of same. This is better known as reducing the dead time. Little argument can be made against this, but its effect on the total head reach is small.

Coupled with all of the aforementioned problems is the additional problem of loss of maneuverability of the ship when the propeller is reversed, the rudder being no longer able to control the ship trajectory. Hence a ship under a crash back maneuver could conceivably render itself helplessly unmaneuverable for as much as 15 minutes, thereby placing itself in extreme danger.

Faced with the above problems, a new idea was brought to light in the addition of a braking device which could be installed on the ship to supplement the ship's own braking force. The advantage of a braking device, other than the obvious opposing force offered by same, is the ability to decrease the speed of the ship from 16 to 6 knots more rapidly than before and hence reduce the time spent in the unmaneuverable stage of deceleration. Further, the braking device itself may help to maneuver the ship during this period of rudder ineffectiveness.

Hence with the above in mind, a flap device was designed which extended from the sides of the ship. The effect on deceleration was substantial but the required size of the flap made the idea impractical.[8] After this a momentum reversing scoop was tested and found similarly effective, but again not practical in that it could not be retracted when not needed.[18] Little else was done and even less was published about the use of a braking device until the writing of this thesis.

The motivation of this thesis is to design a hydrodynamic brake of the flat-plate type which would rectify the problems incurred in the two preceding designs. Numerous configurations within several basic arrays of small flat plates (hereinafter referred to as "platelets") set perpendicular to the direction of motion of the ship were to be affixed to the keel of a supertanker as modeled by a large flat plate (hereinafter referred to as the "plate") and the drag induced by these platelets was to be measured. With this data, the reduction of the head reach of a supertanker was to be calculated and thus the value of the array evaluated.

PROCEDURE

The object of this thesis was to investigate the increased drag on a supertanker, as modeled in the M.I.T. propeller tunnel, by the installation of semi-tandem platelets along its keel. A large mild steel plate whose dimensions were constrained by the size of the propeller tunnel test section was manufactured to a thickness which would preclude buckling of same in the face of high velocities. Platelets were also manufactured of mild steel and were of size 1" x 1" x 1/8".

The platelets were affixed to the plate in various arrays for testing by use of epoxy. Then the entire unit was inserted into the propeller tunnel test section supported by the dynamometer rod. Due to the excessive weight of the unit, a supplementary support was needed to relieve the stress in the dynamometer rod/flange weld. Hence in order to provide maximum support with minimum resistance to flow, a "V" shaped device was designed and located at approximately the center of gravity of the unit; i.e., plate and platelets.

Once in place, a flow was induced past the array and the drag sought. The force on the array was transmitted via the six component hydrofoil dynamometer to an upper load cell of 100 lbf capacity and a lower load cell of 200 lbf capacity. Two load cell outputs were necessary in order to solve the force/moment similtaneous equations. In turn,

the load cells transmitted an electrical signal to their respective Digital Strain Gage Indicator, which displayed the drag force of the array directly in counts. A calibration process employing hanging weights was used prior to experimentation to develop a graph of lbf vs. counts to be used in deciphering the Digital Strain Gage Indicator output.

Drag data was obtained for a specific configuration for speeds corresponding to that of the parent ship range of two to sixteen knots inclusive. Initially, a large number of platelets were affixed in an array and, as the experiment proceeded, platelets were removed until a bare plate condition was reached. This was done in order to conserve time and decrease experimental error. Finally, the drag for the bare plate condition was subtracted from the various configurations at corresponding speeds and the drag of the platelets themselves resulted; i.e., corrected drag.

For each configuration within each array, the value of the coefficient of drag, C_D, based on the total area normal to the flow was calculated. A graphical display was then made to determine the average coefficient of drag for a particular configuration of a particular array.

The above was accomplished for several arrays designated as 1" spacing, 1"* spacing, 1 1/4" spacing and no spacing, and the results tabulated. Finally, based on this graphical and tabular analysis, the value of the resulting head reach of a supertanker with each specific configuration affixed to

to its keel was calculated and the value of each array in reducing same resolved.

Several questions arose during the progress of the experimentation which warranted answering. First, since the Reynolds number was chosen as the quantity to conserve in order to insure dynamic similarity, the Froude number was discarded, the conservation of both Re and Fr requiring the use of a different fluid in the model and the prototype. The error induced by this assumption was questioned but nullified by the preservation of no free surface inside the propeller tunnel. This prohibition of a free surface eliminated the importance of Froude number in the experiment. Further, for the ladden ship, the keel is so far under the free surface that the free surface motions are unimportant and hence the Froude number is irrelevant as far as the platelets are concerned.

The second question of merit was whether or not the platelets as designed would be enveloped by the boundary layer and hence rendered barren in drag production. The following calculation answers this query:

<u>Assume turbulent B.L.:</u>

$$\frac{\delta}{x} = 0.379 \left(\frac{\nu}{V x}\right)^{1/5}$$

$$= 0.379 \left(\frac{\nu}{V}\right)^{1/5} x^{4/5}$$

$$= 0.379 \left(\frac{1.21 \times 10^{-5}}{16.3}\right)^{1/5} x^{4/5}$$

$$\therefore \delta = 2.26 \times 10^{-2} x^{4/5}$$

Since the first row of platelets is located at seven inches along the length of the plate, the boundary layer thickness there; i.e., at x = 7 inches, would be:

$$\delta = 2.26 \times 10^{-2} (7)^{4/5}$$

$$\therefore \delta = 0.107 \text{ in.}$$

Now the depth of the platelets being one inch, it is seen that the platelets will not be enveloped. Obviously, a laminar boundary layer would yield an even less severe situation.

1" SPACING ARRAY - 8 PLATELET CONFIGURATION

SIDE AND BOTTOM VIEWS

SCALE: 1" = 7"

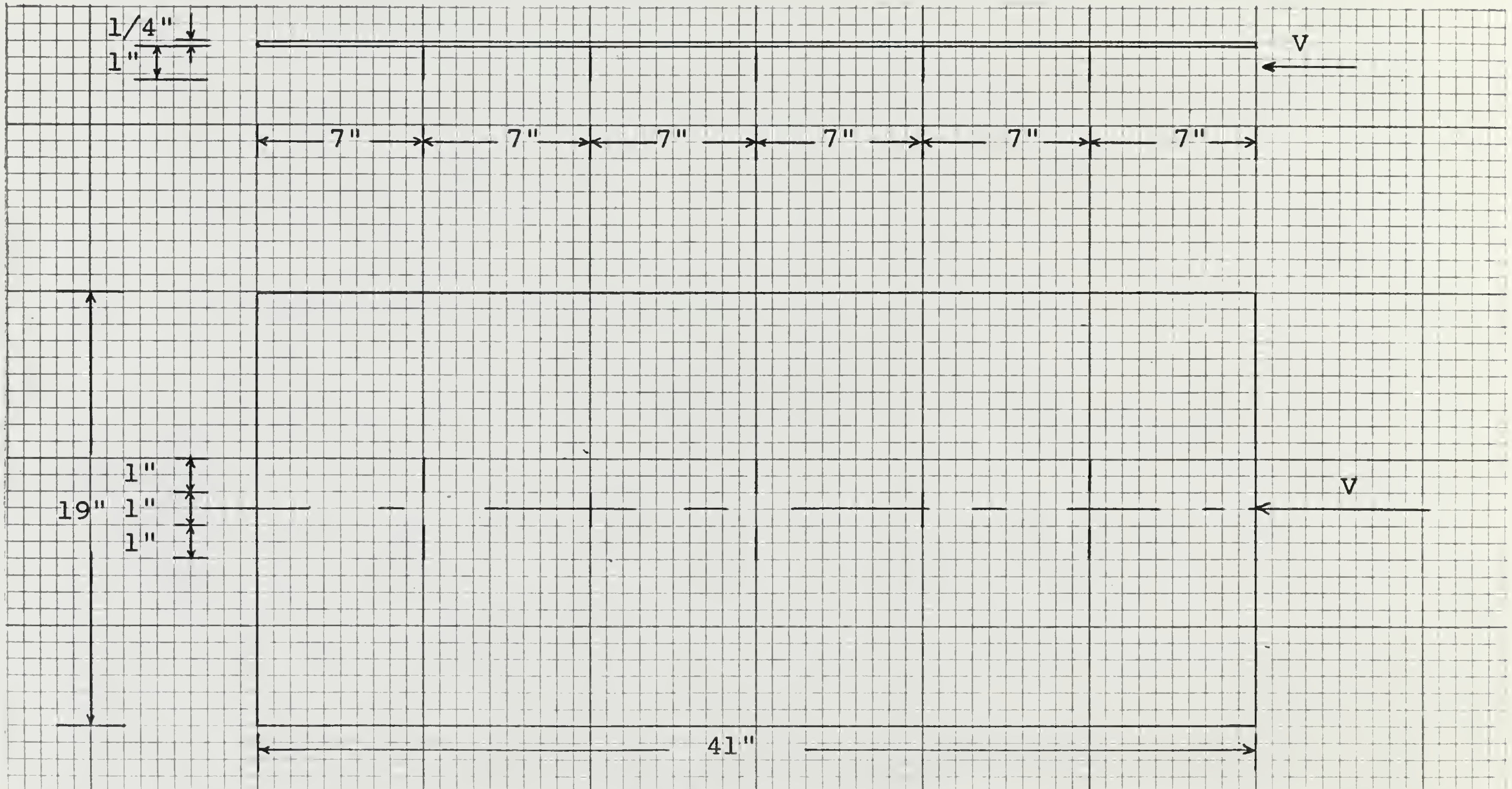
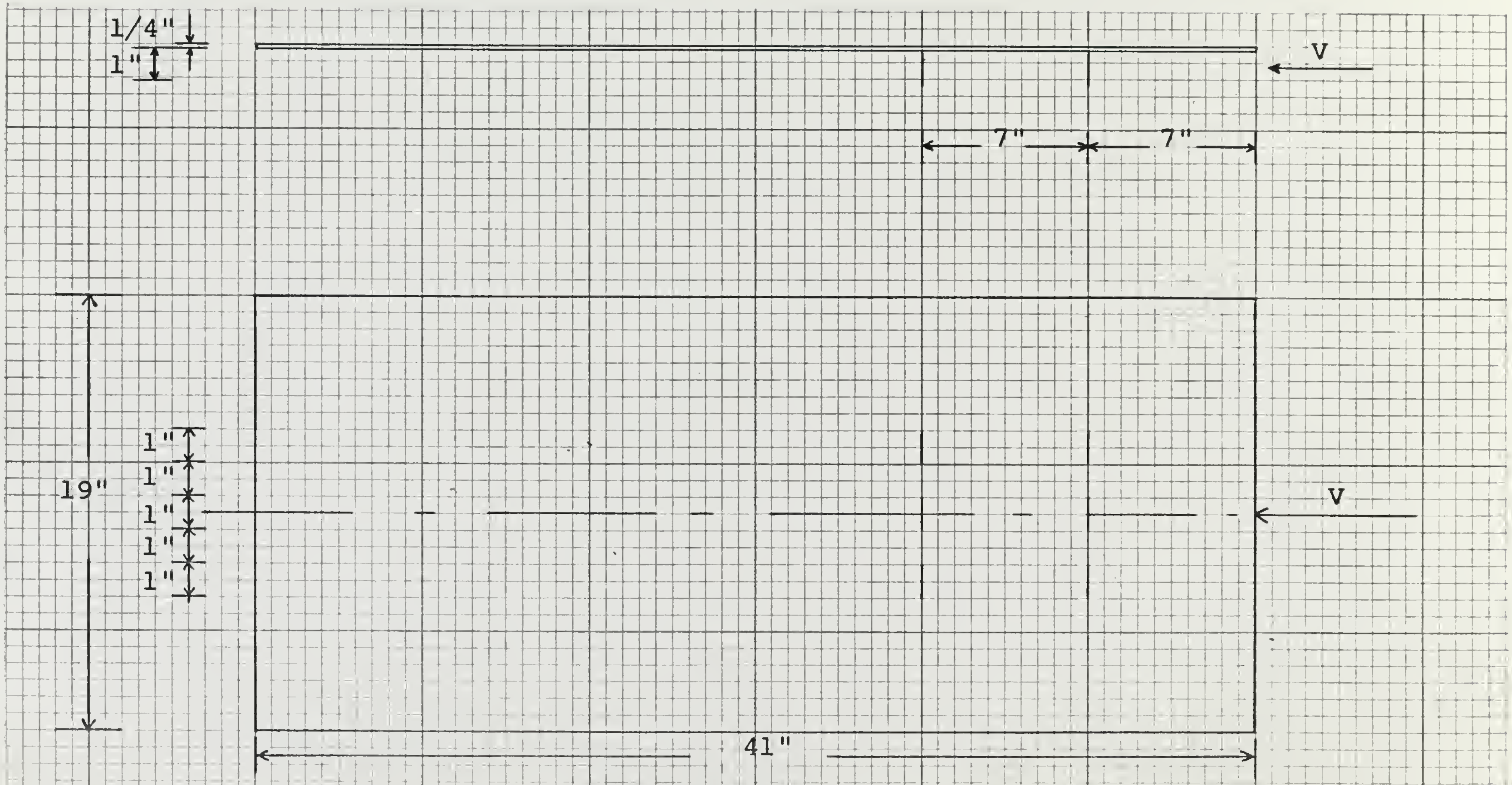


FIGURE 1

1"* SPACING ARRAY - 6 PLATELET CONFIGURATION

SIDE AND BOTTOM VIEWS

SCALE: 1" = 7"



F I G U R E 2

1 1/4" SPACING ARRAY - 5 PLATELET CONFIGURATION

SIDE AND BOTTOM VIEWS

SCALE: 1" = 7"

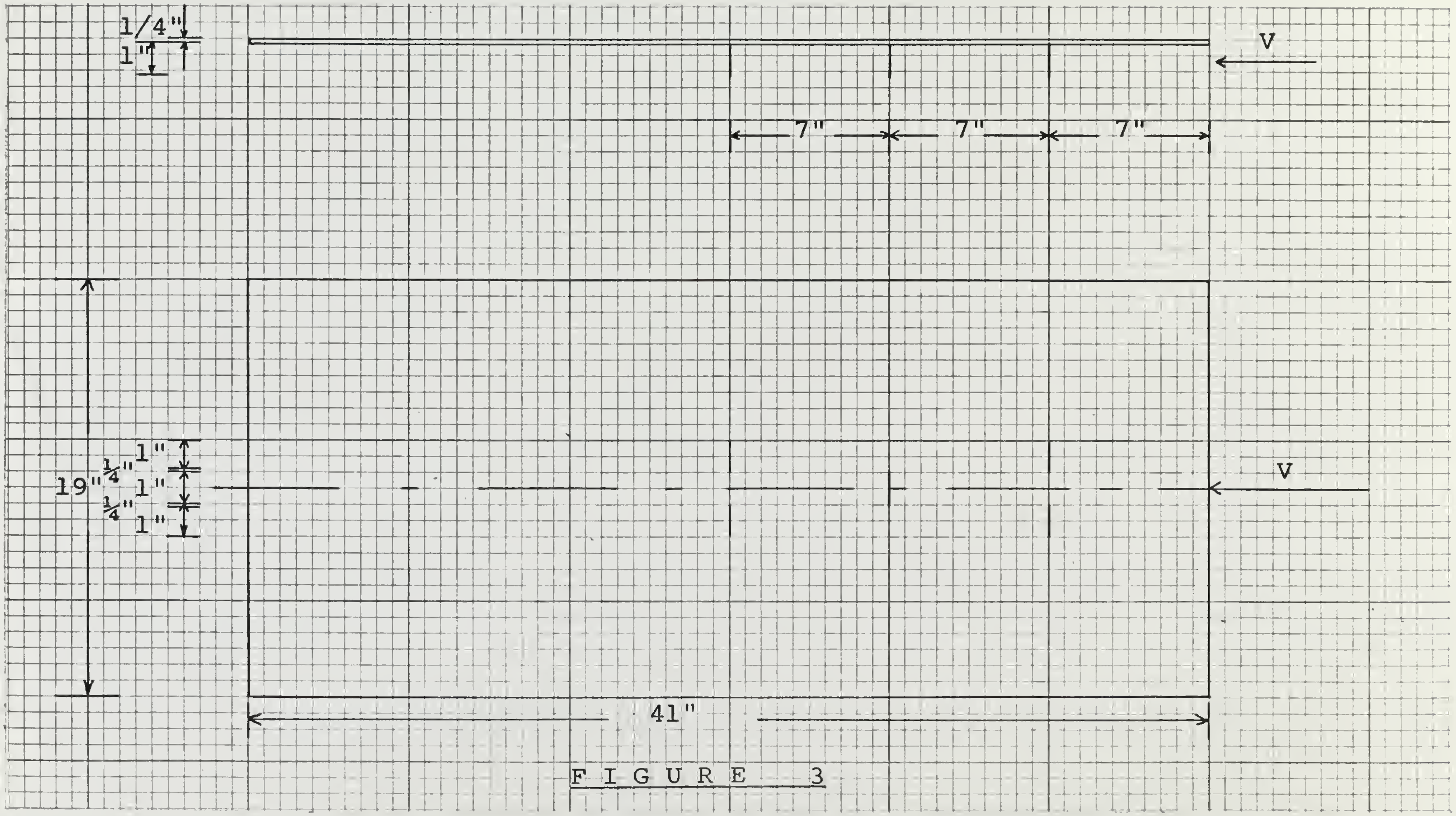


FIGURE 3

NO SPACING ARRAY - 17 PLATELET CONFIGURATION

SIDE AND BOTTOM VIEWS

SCALE: 1" = 7"

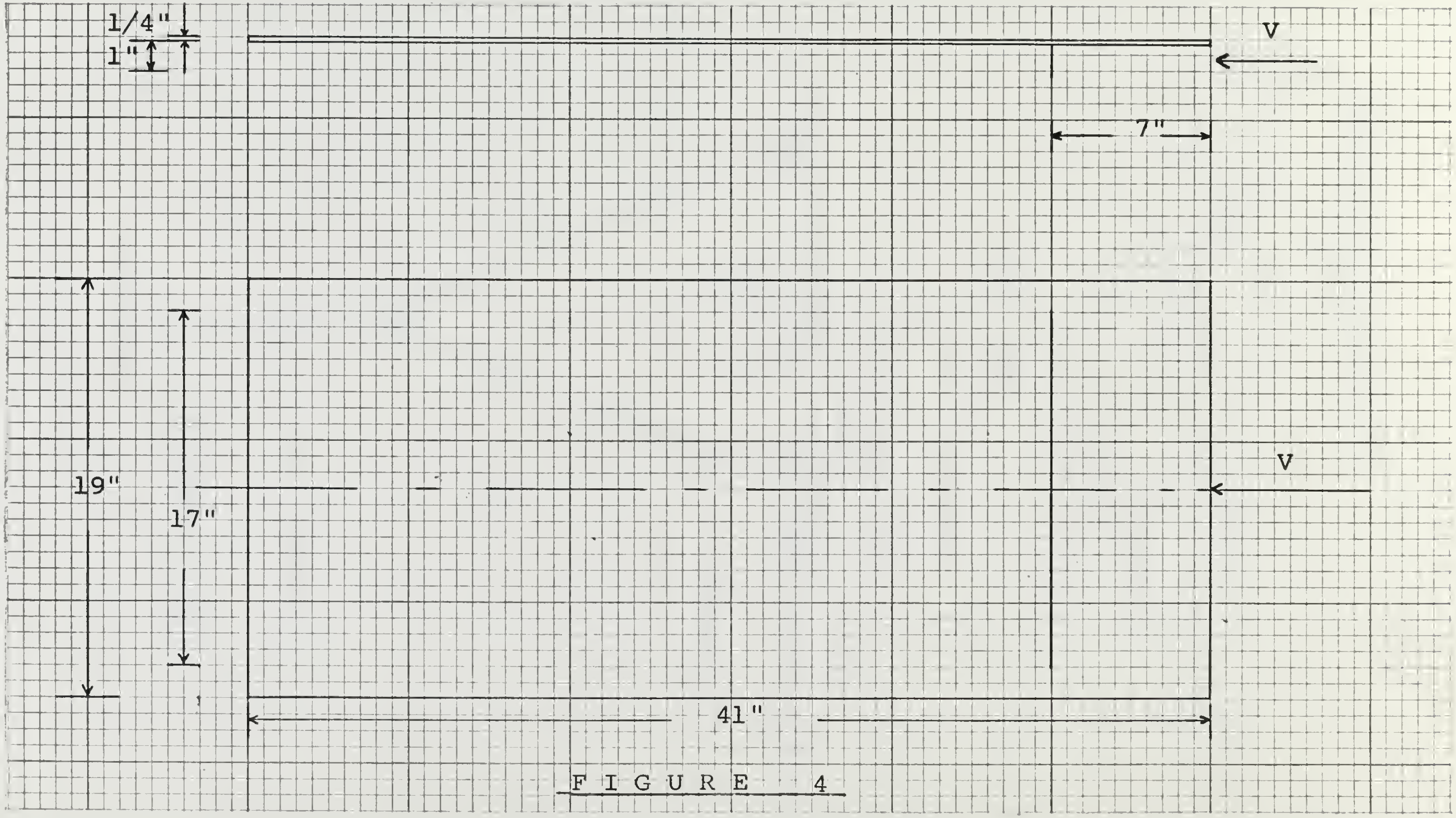


FIGURE 4

DESCRIPTION OF APPARATUS

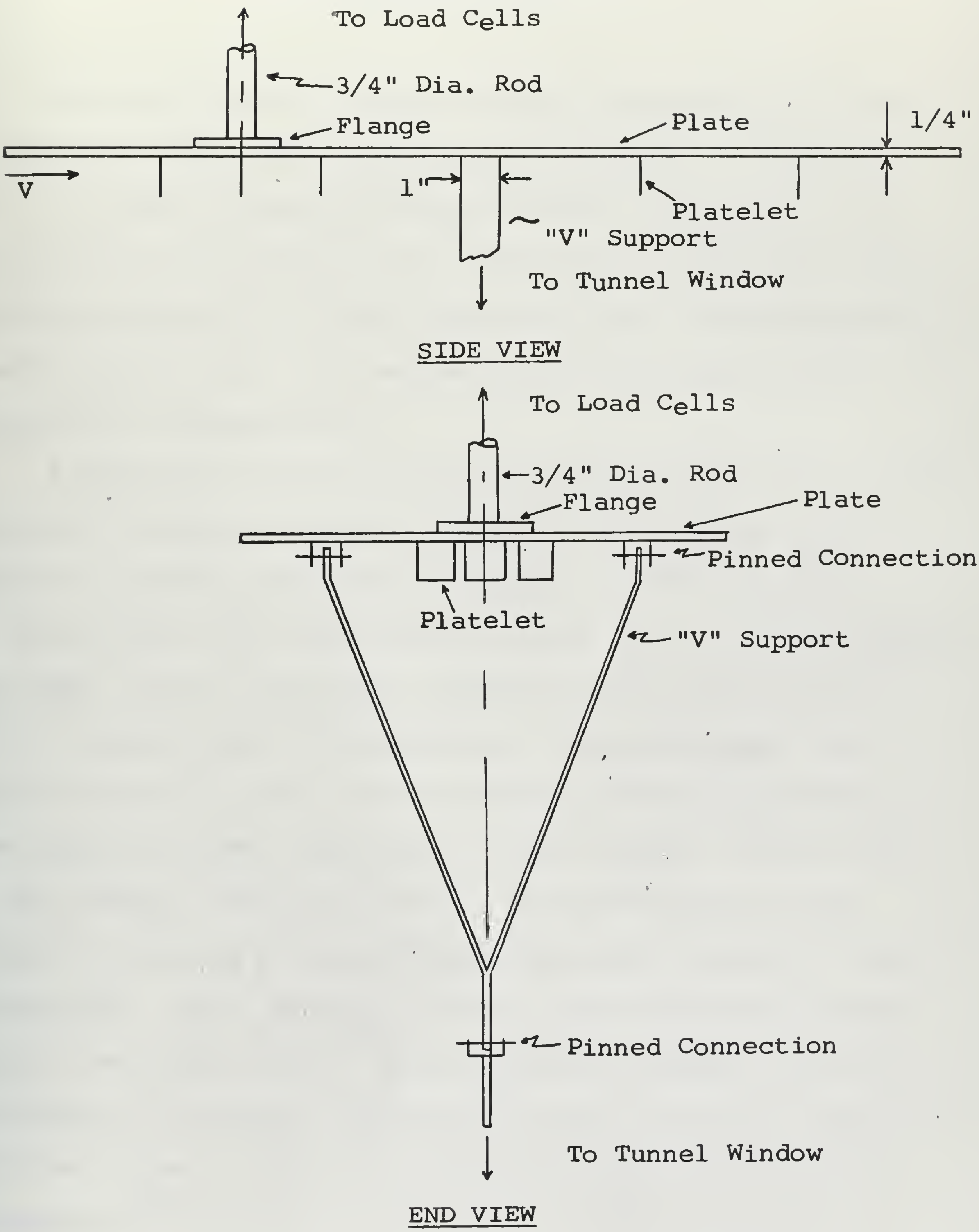


FIGURE 5

RESULTS

The drag generated by the various configurations within the arrays tested was deciphered and tabulated in Appendix VII. In these tables the column entitled "Drag Corr." indicates the restraining force produced by the platelets themselves as mounted. For each speed analyzed, the corresponding coefficient of drag, C_D, was calculated and additionally tabulated in Appendix VII.

A graphical analysis of the various configurations' coefficients of drag was made to determine the average C_D for each; the results are found in Figures 6 to 28 inclusive. In each figure, the coefficient of drag, C_D, is plotted against the model speed in feet per second where the speed range is two to sixteen knots corresponding to the prototype. As seen in these figures, the coefficient of drag fluctuates at low speeds and then stablizes at higher speeds. This is due to the reduced sensitivity of the instrumentation at low speeds as discussed in the "Recommendations" section of this manuscript. Quite obviously, from a fluid mechanics standpoint, the coefficient of drag should be constant for each configuration although differing in value due to the high Reynolds number involved in each case, which dictates this phenomenon.[7]

Finally, the value for the reduction of head reach under the influence of each configuration was found and included in Appendix VII. in terms of percent of head reach obtained without the aid of a breaking device.

1" SPACING ARRAY - 1 PLATELET C_D

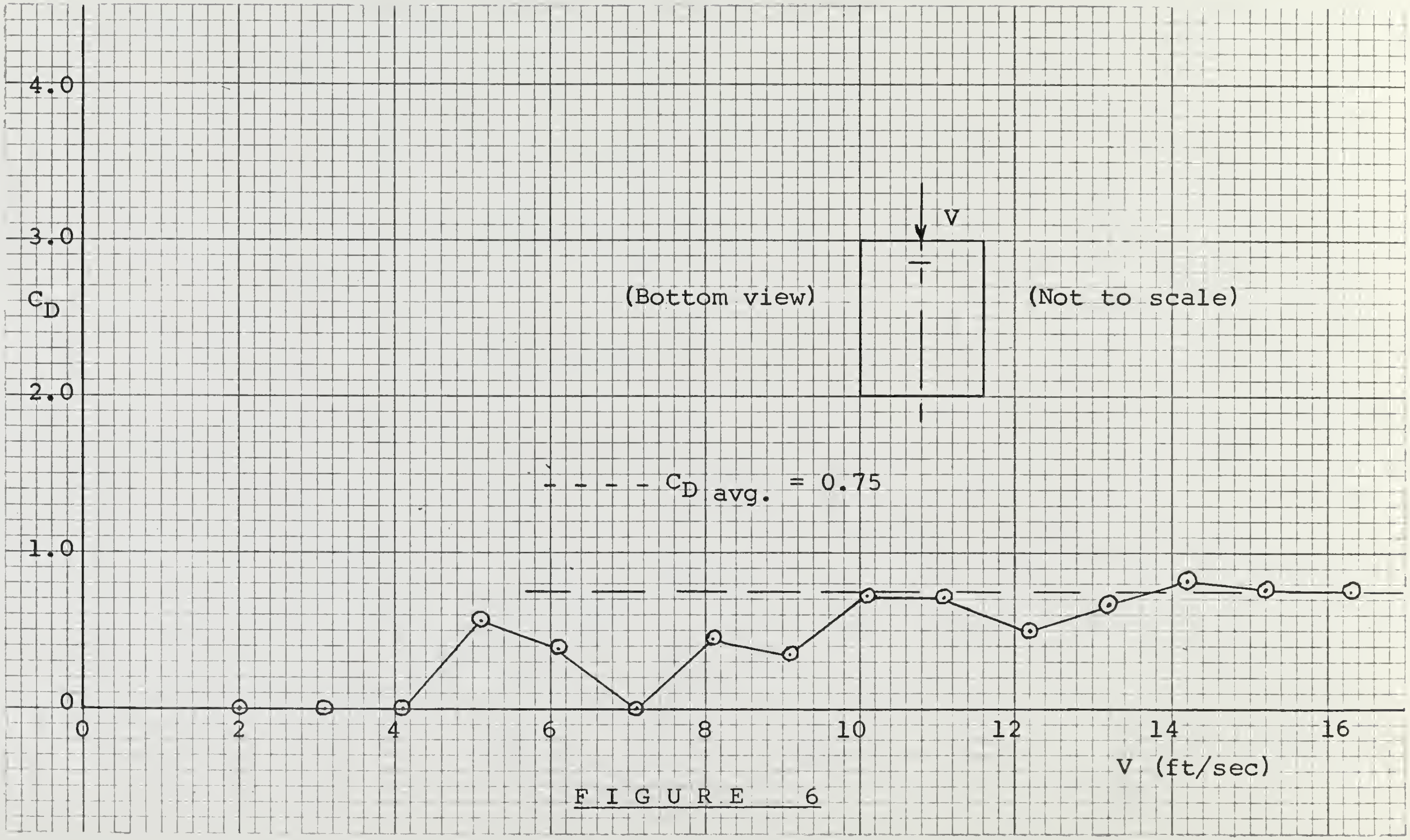


FIGURE 6

1" SPACING ARRAY - 2 PLATELETS C_D

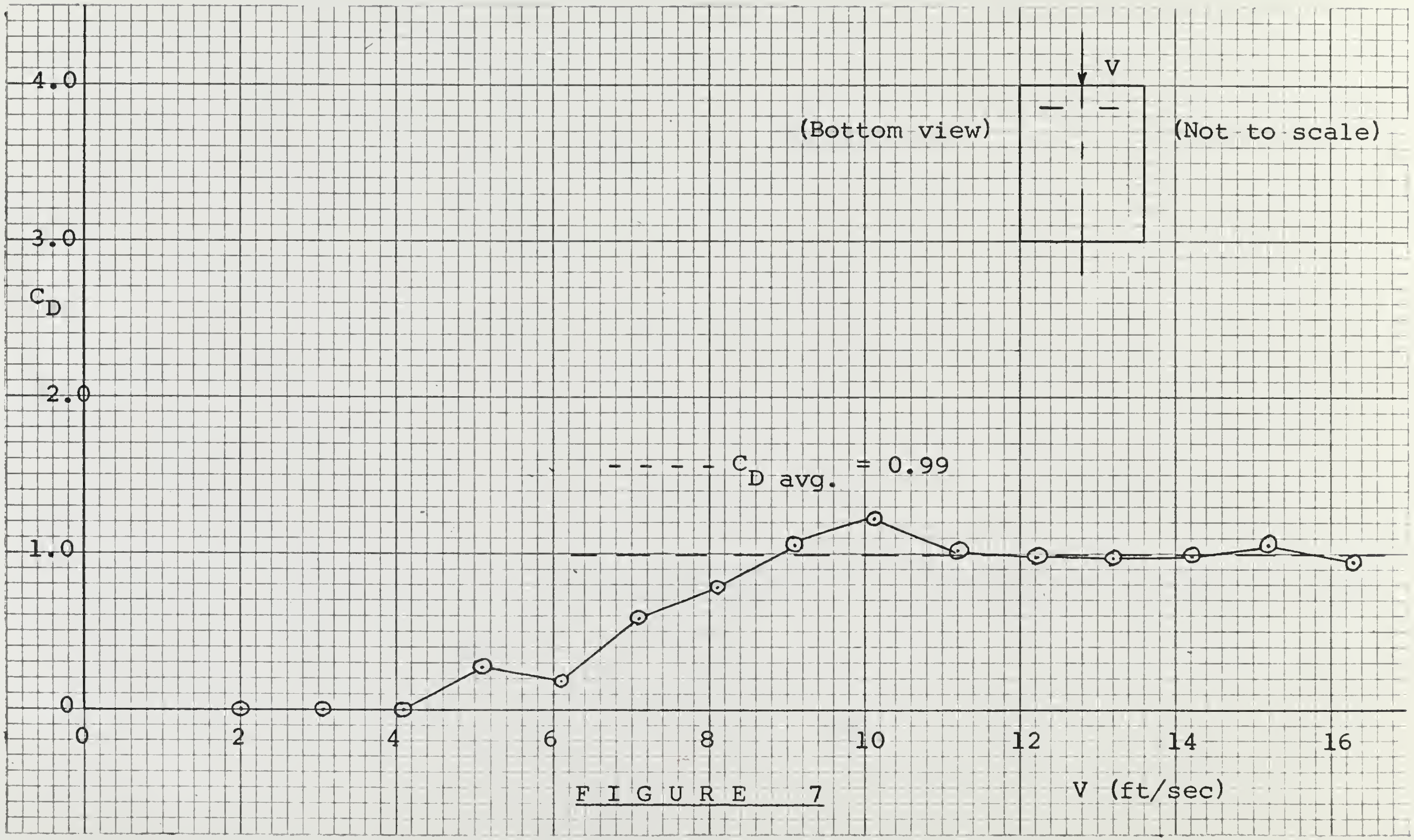


FIGURE 7

1" SPACING ARRAY - 3 PLATELETS C_D

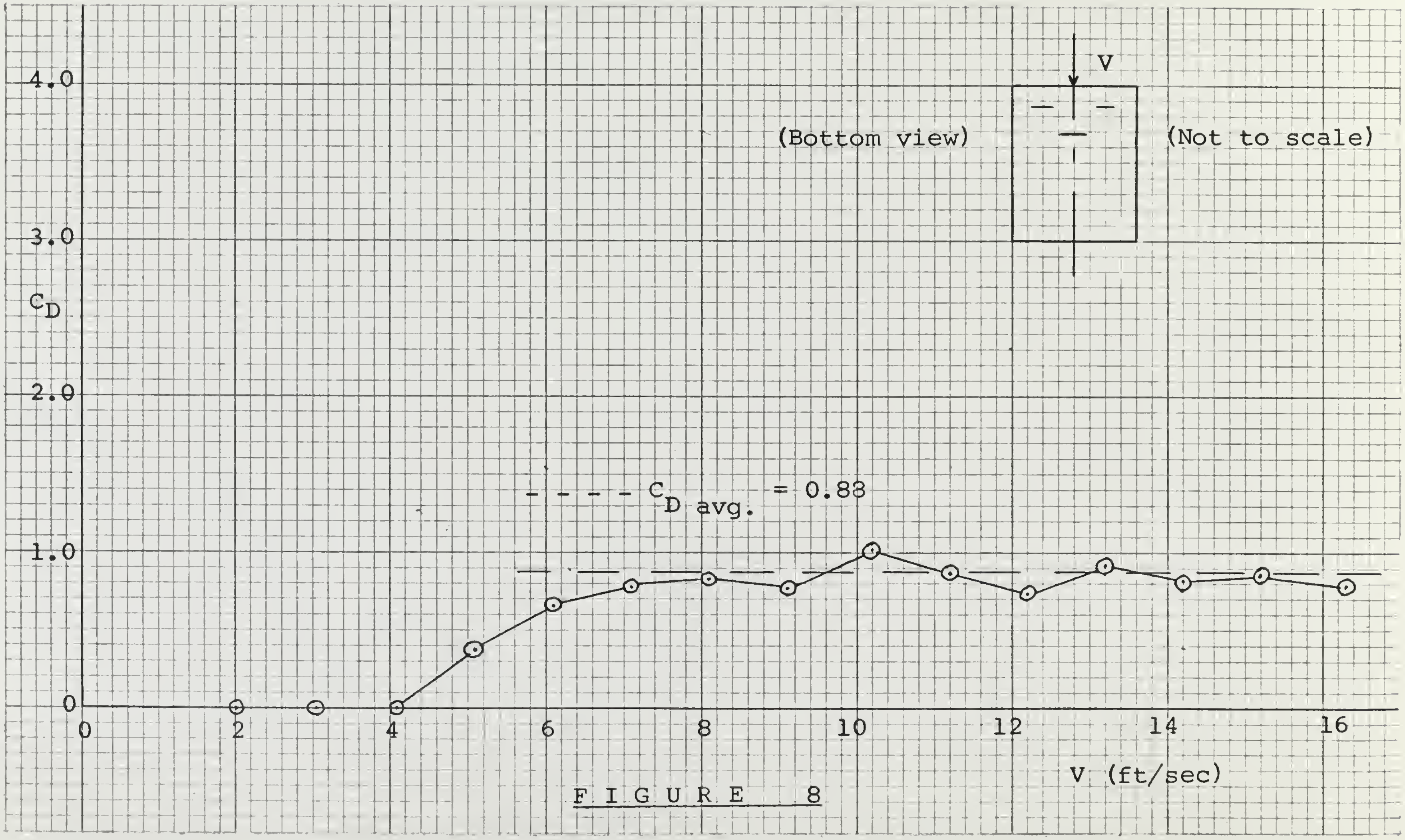


FIGURE 8

1" SPACING ARRAY - 5 PLATELETS C_D

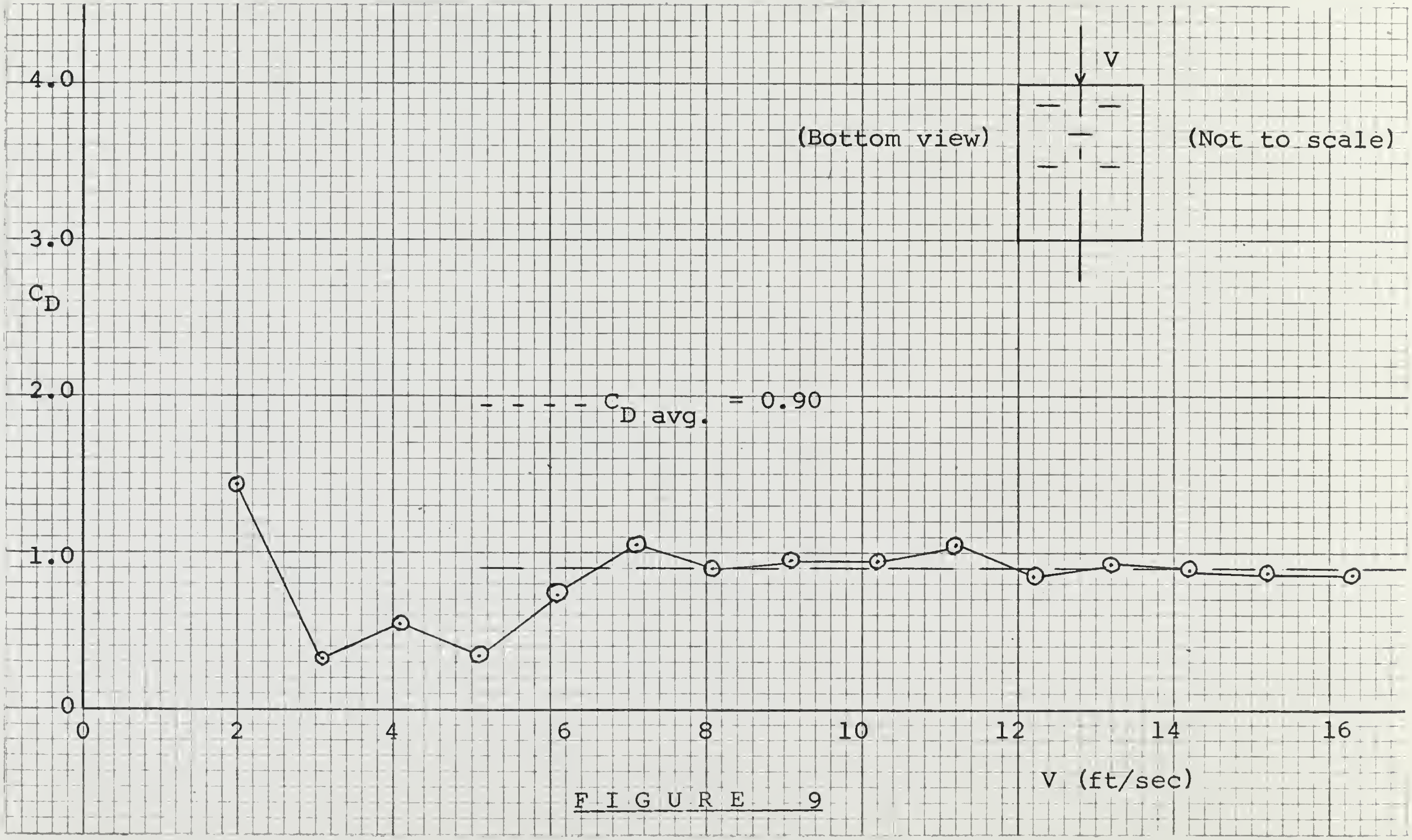


FIGURE 9

1" SPACING ARRAY - 6 PLATELETS C_D

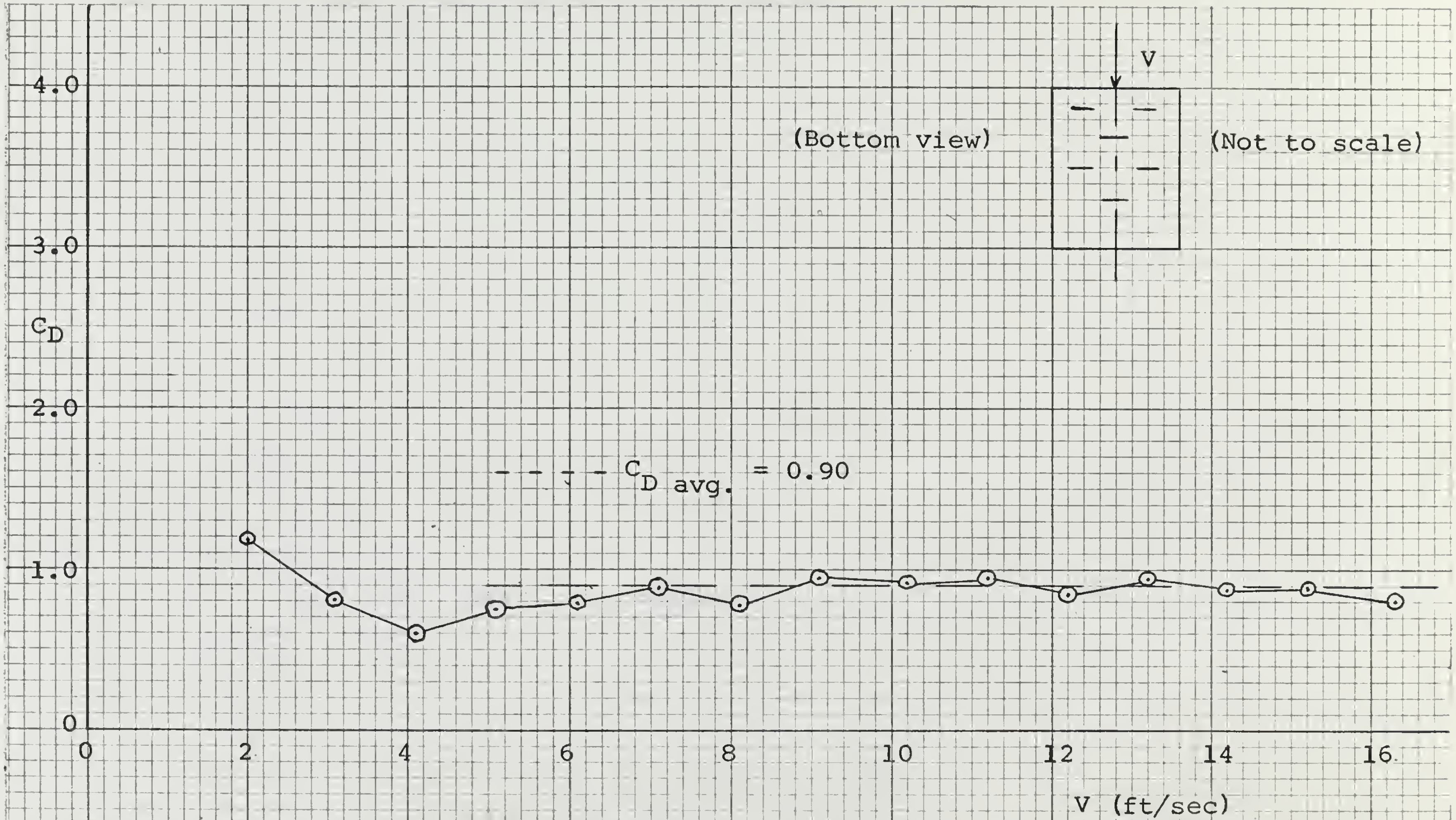


FIGURE 10

1" SPACING ARRAY - 7 PLATELETS C_D

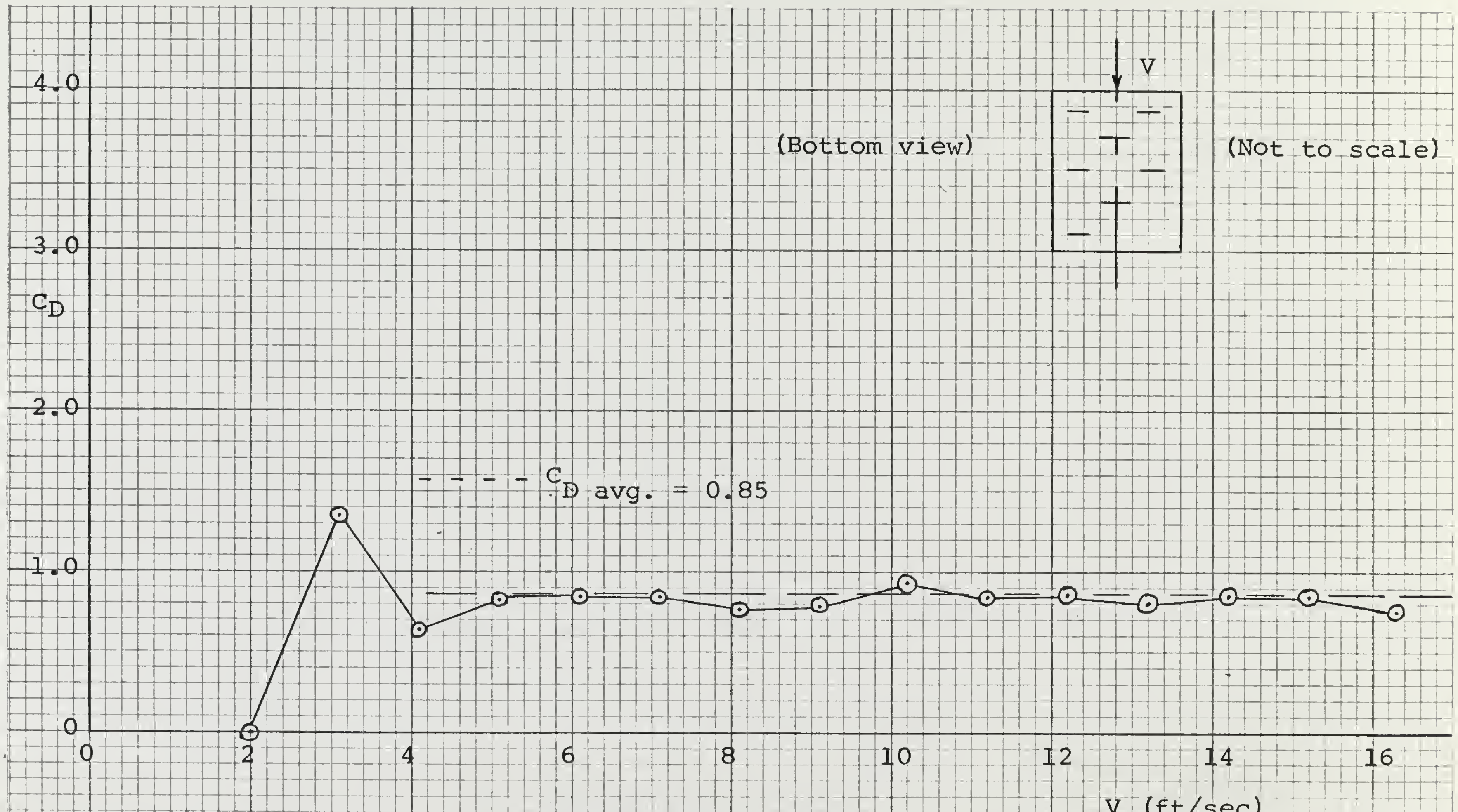


FIGURE 11

1" SPACING ARRAY - 8 PLATELETS C_D

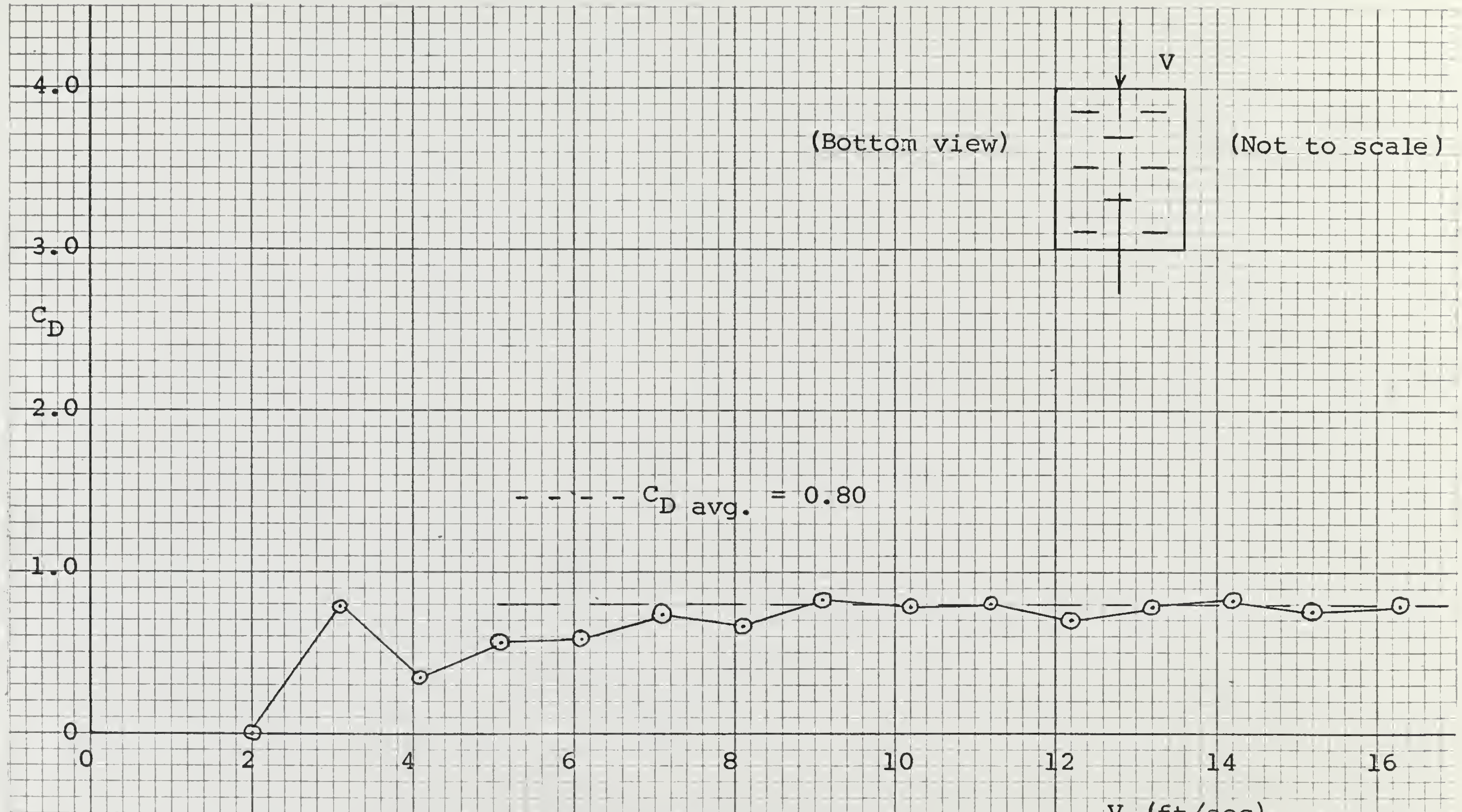
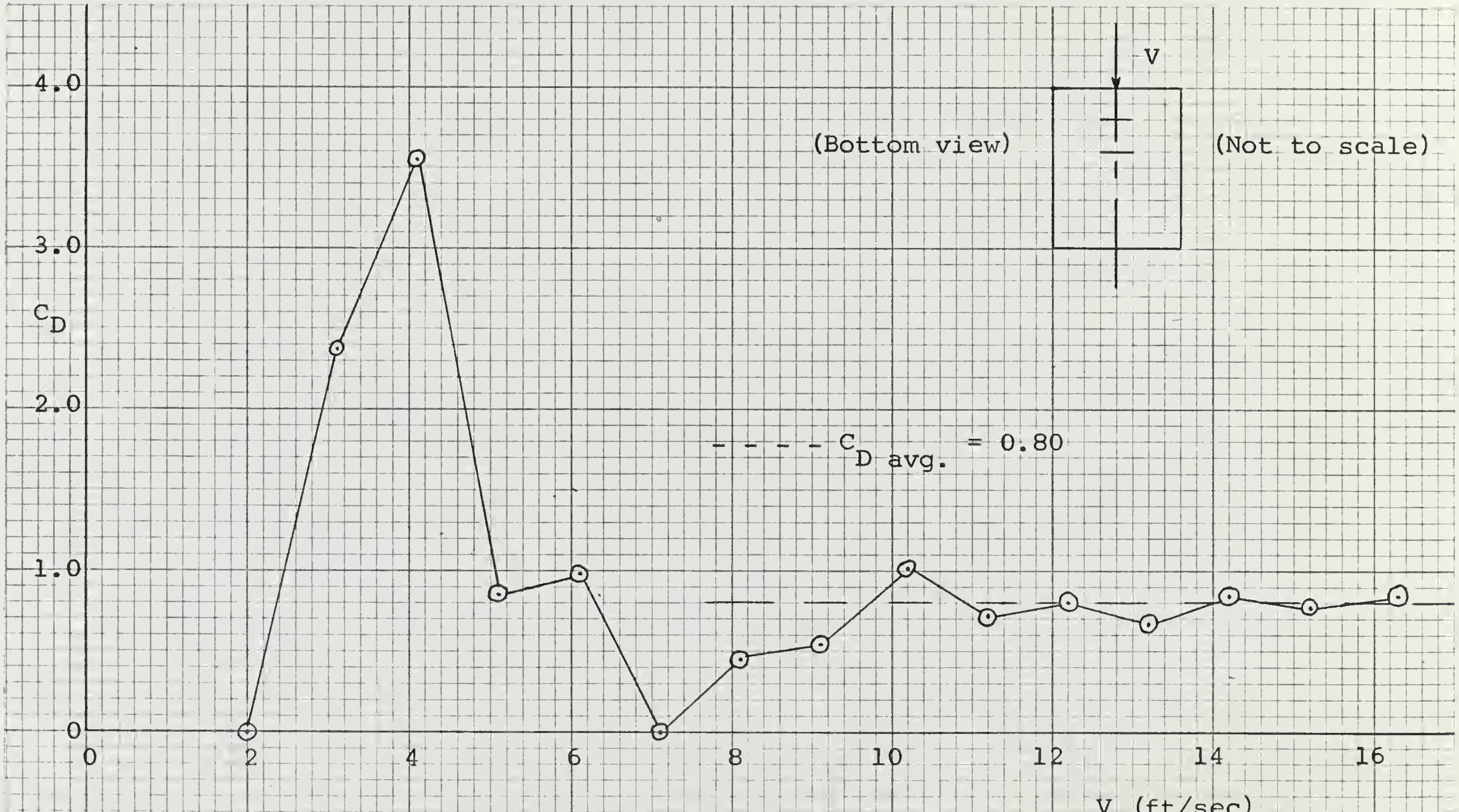


FIGURE 12

1"* SPACING ARRAY - 2 PLATELETS C_D



F I G U R E 1 3

1"* SPACING ARRAY - 4 PLATELETS C_D

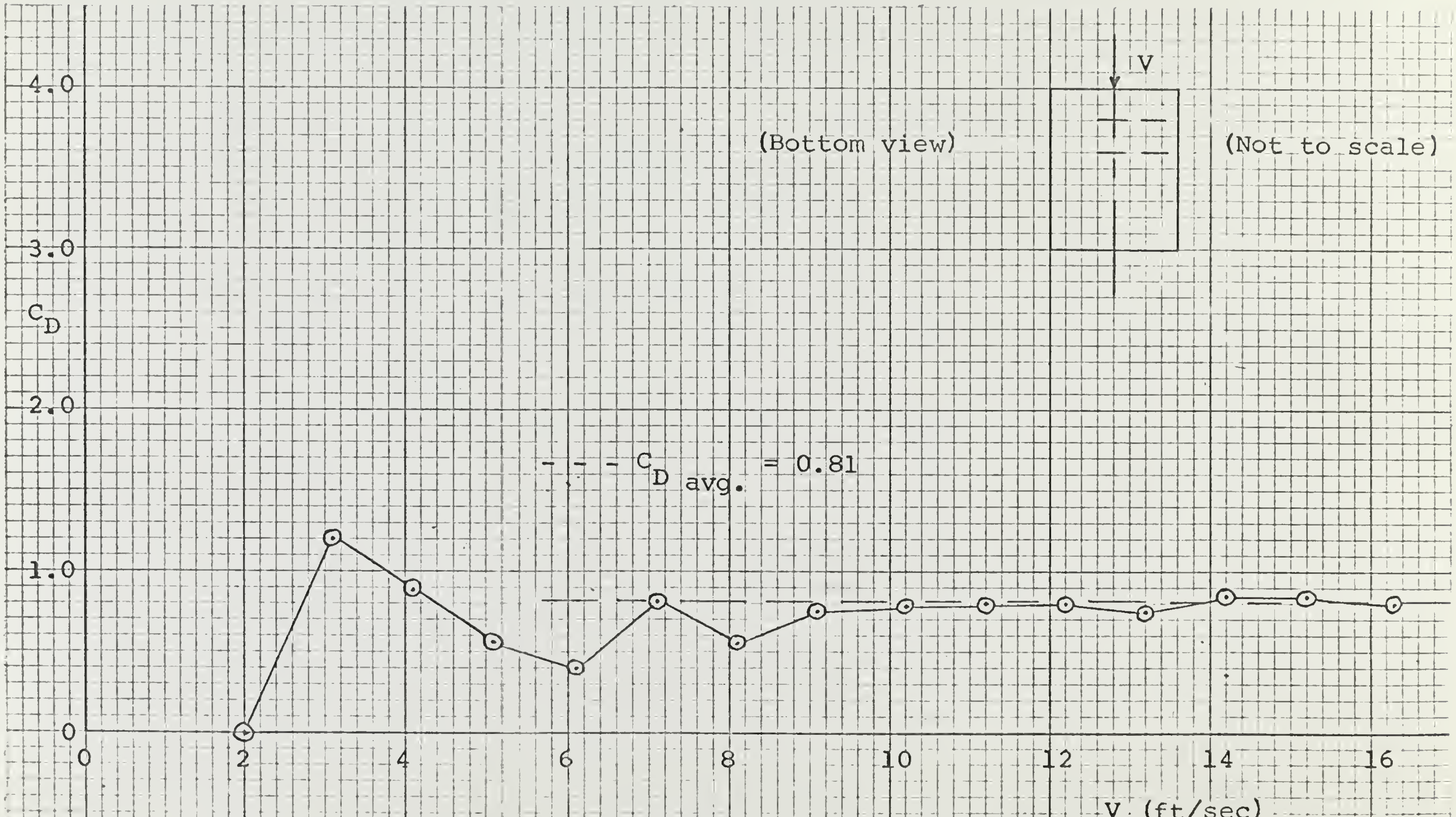


FIGURE 14

1"* SPACING ARRAY - 6 PLATELETS C_D

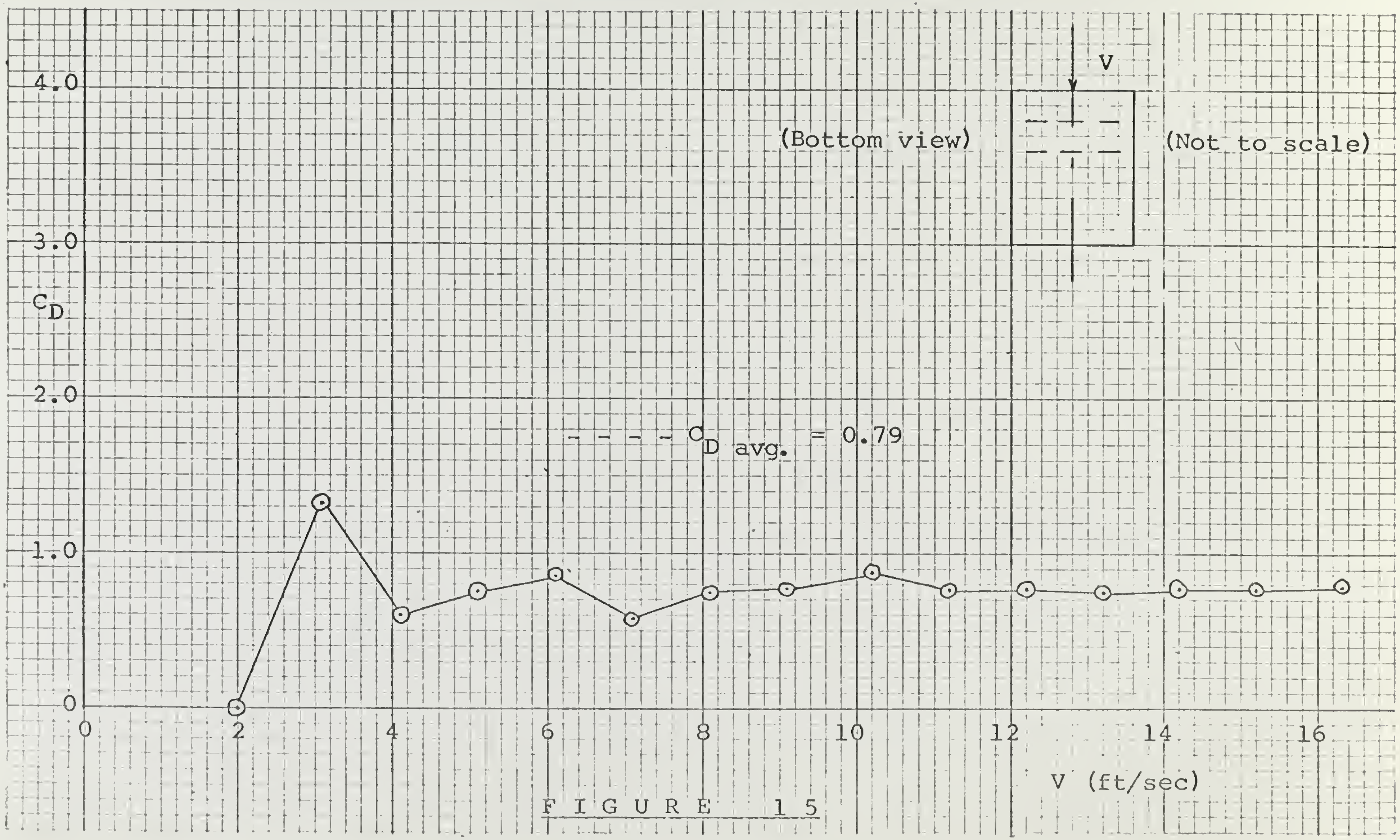


FIGURE 15

1 1/4" SPACING ARRAY - 2 PLATELETS C_D

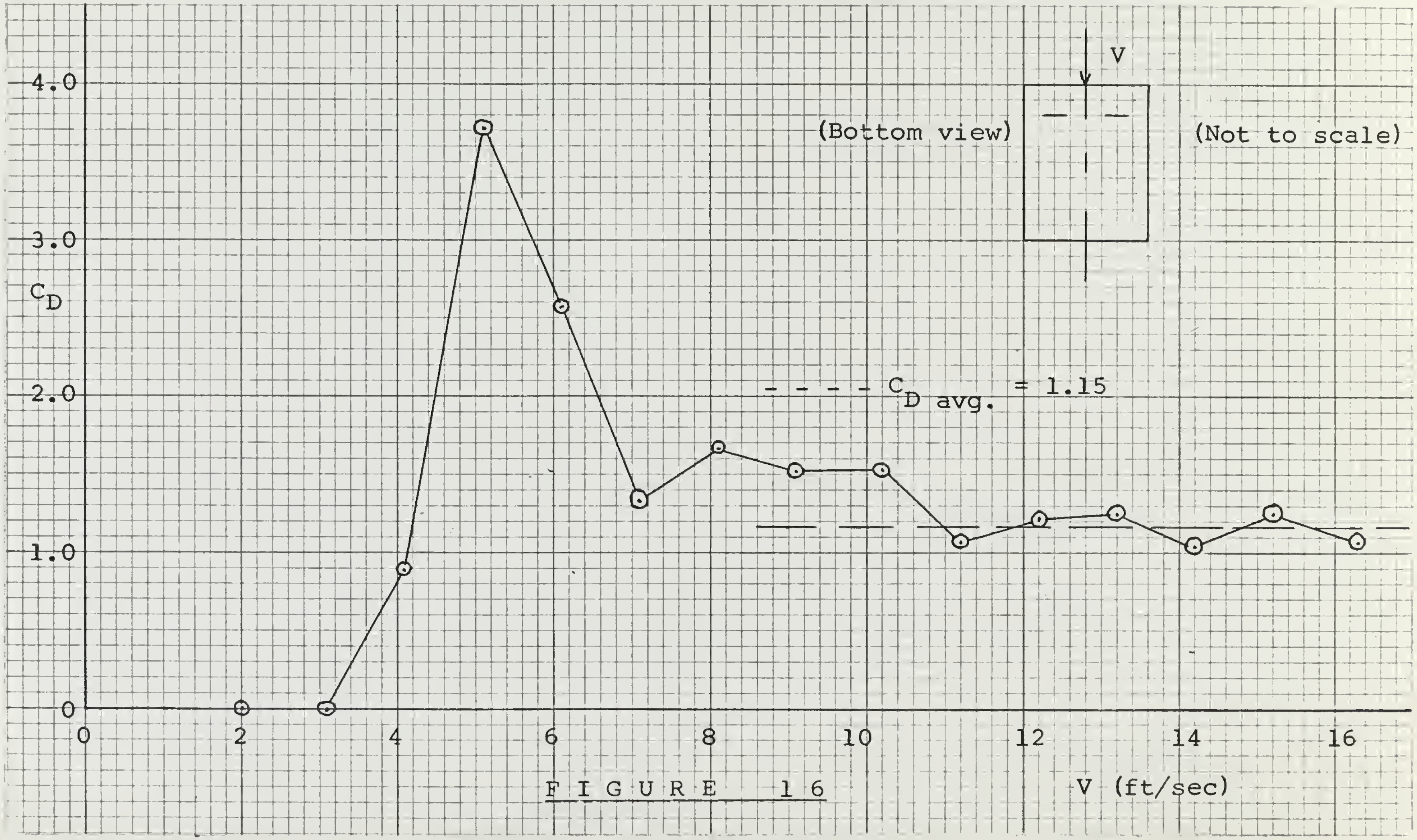


FIGURE 16

1 1/4" SPACING ARRAY - 3 PLATELETS C_D

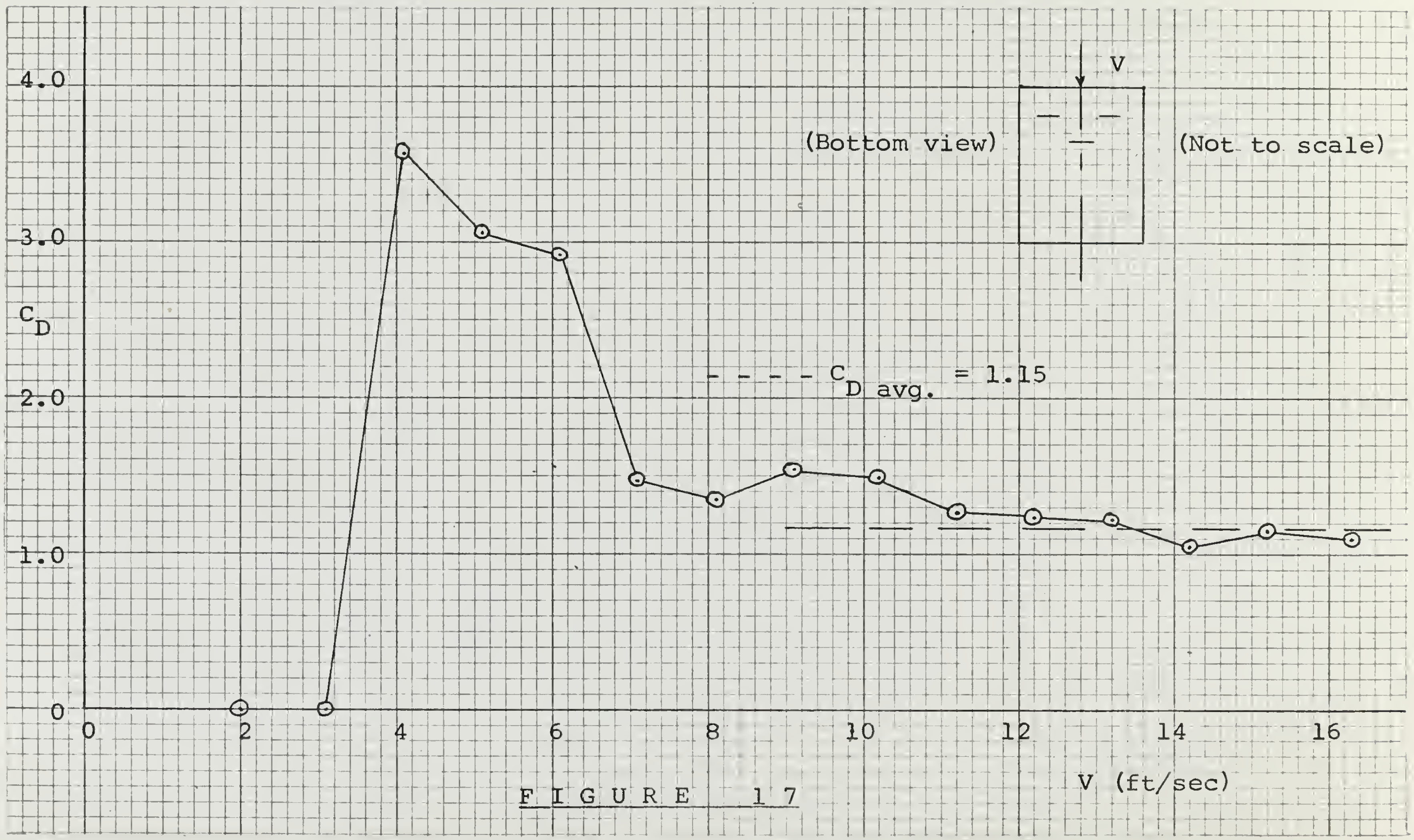


FIGURE 17

1 1/4" SPACING ARRAY - 4 PLATELETS C_D

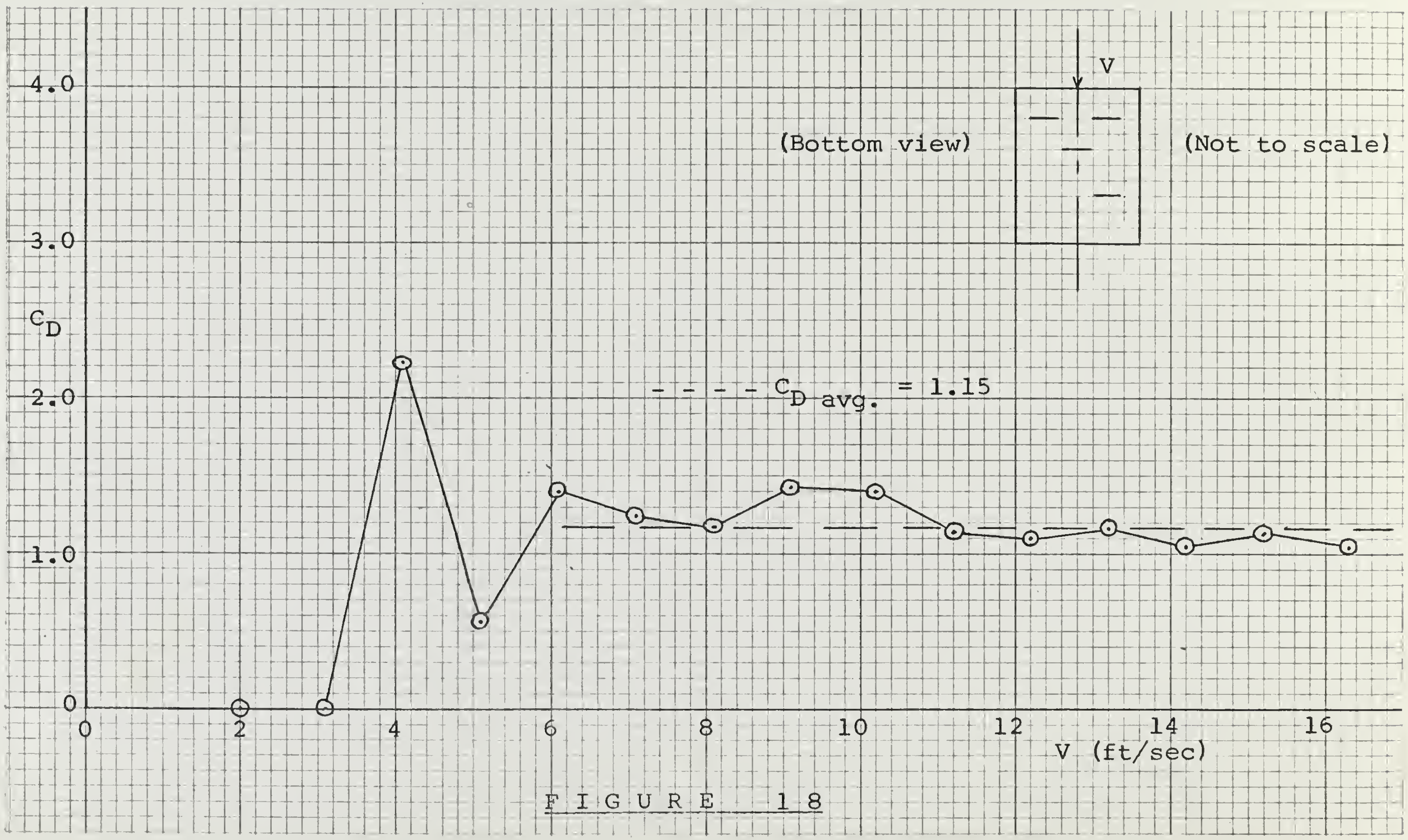
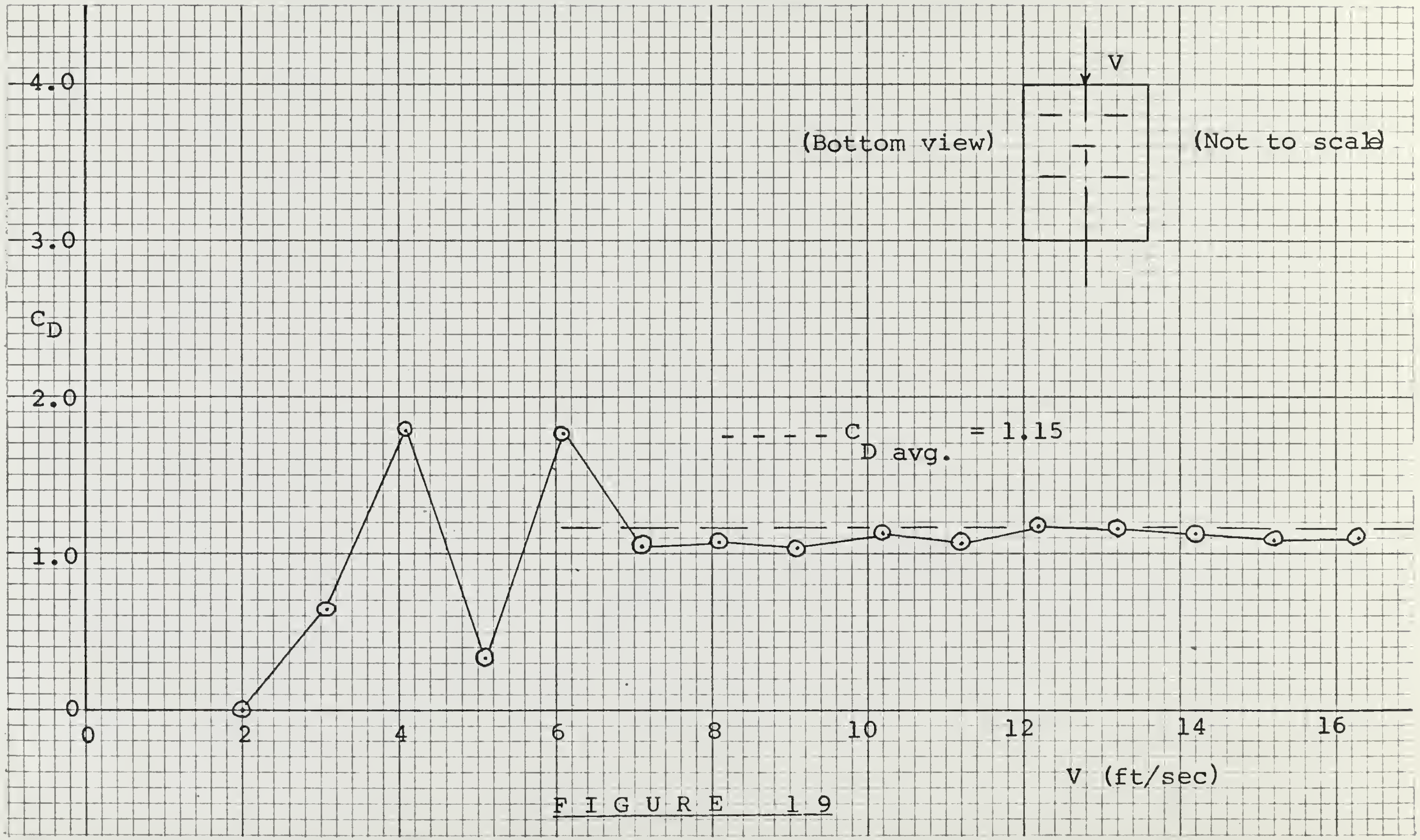


FIGURE 18

1 1/4" SPACING ARRAY - 5 PLATELETS C_D



F I G U R E 1 9

NO SPACING ARRAY - 2 PLATELETS C_D

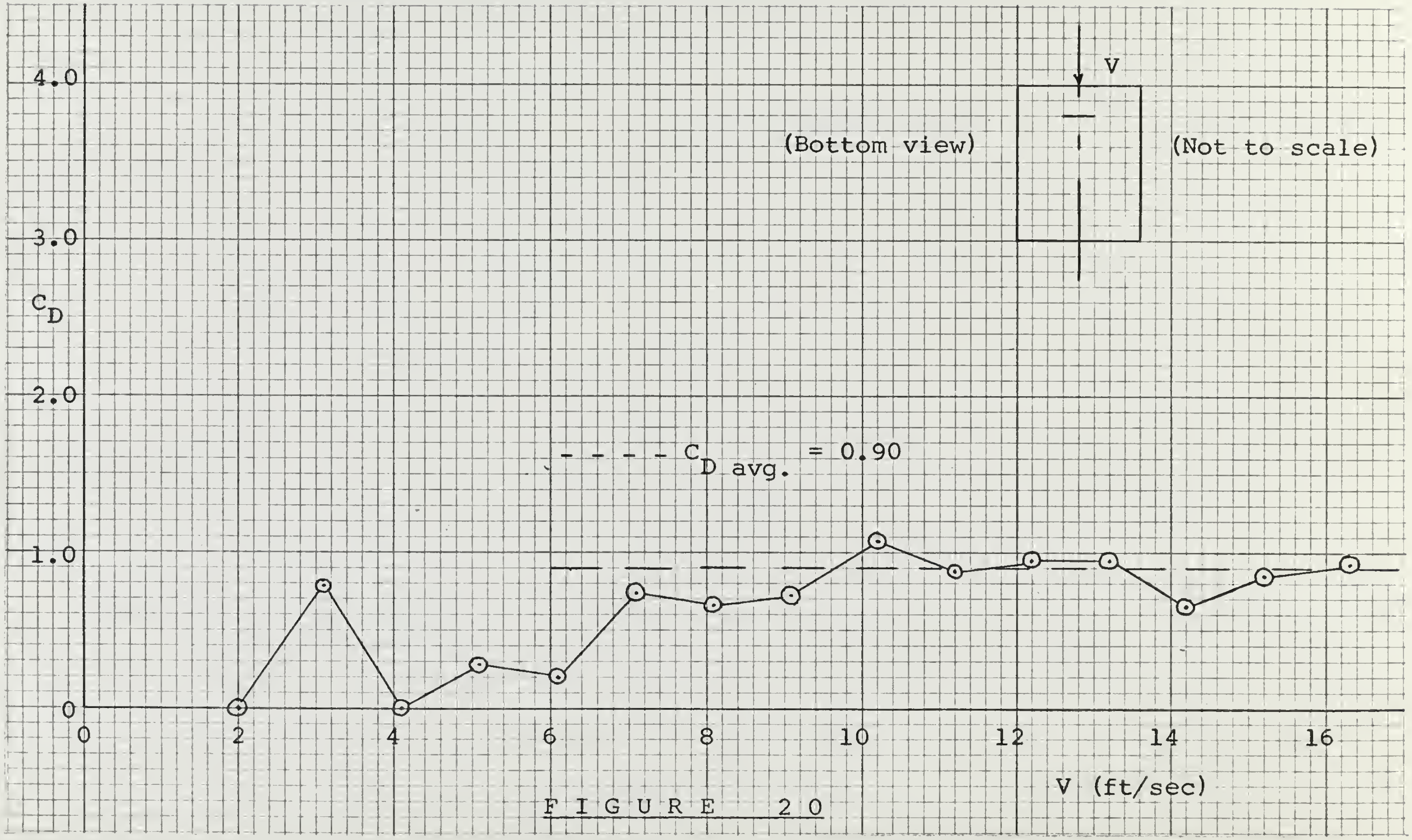


FIGURE 20

NO SPACING ARRAY - 3 PLATELETS C_D

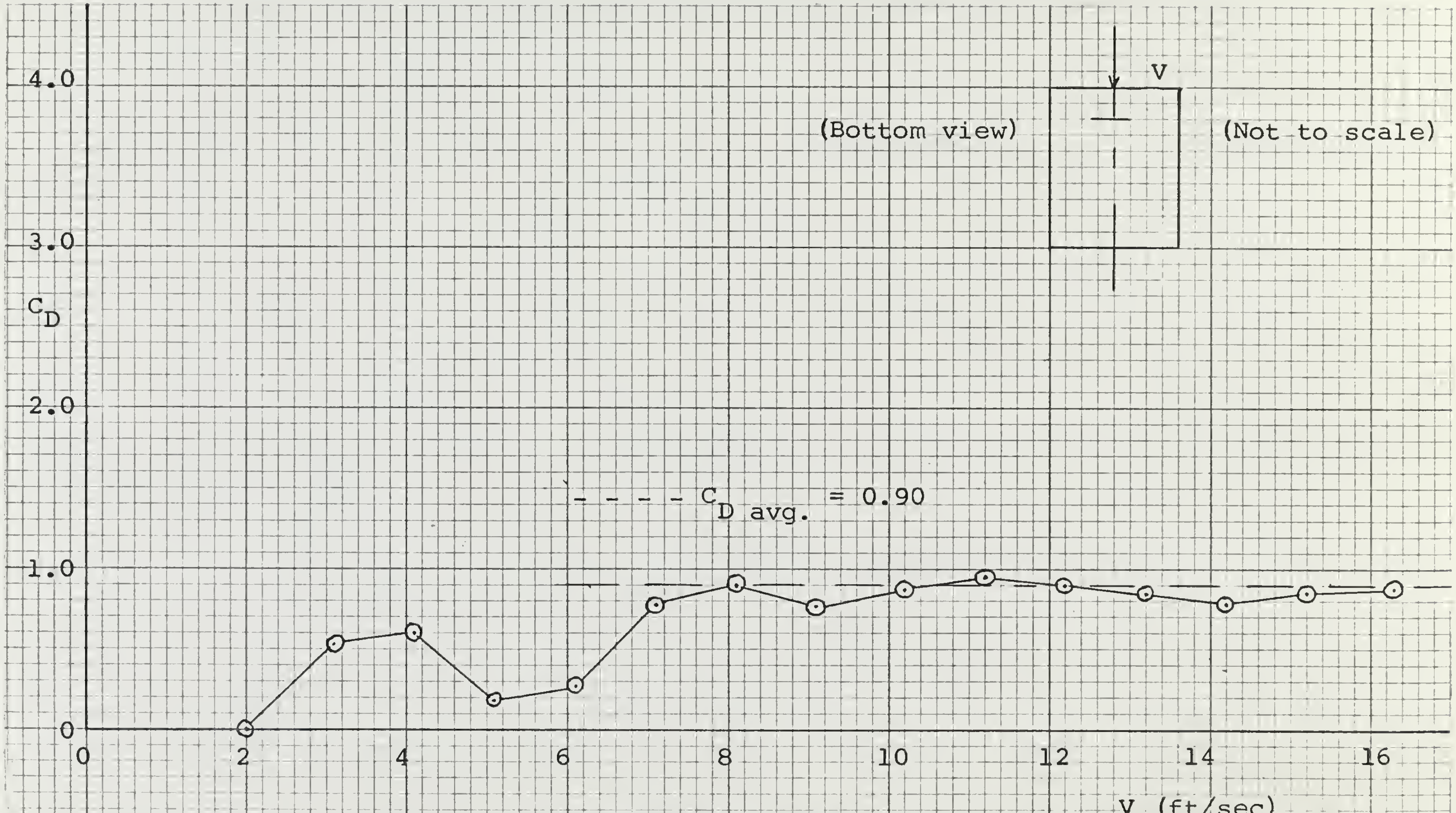


FIGURE 21

NO SPACING ARRAY - 5 PLATELETS C_D

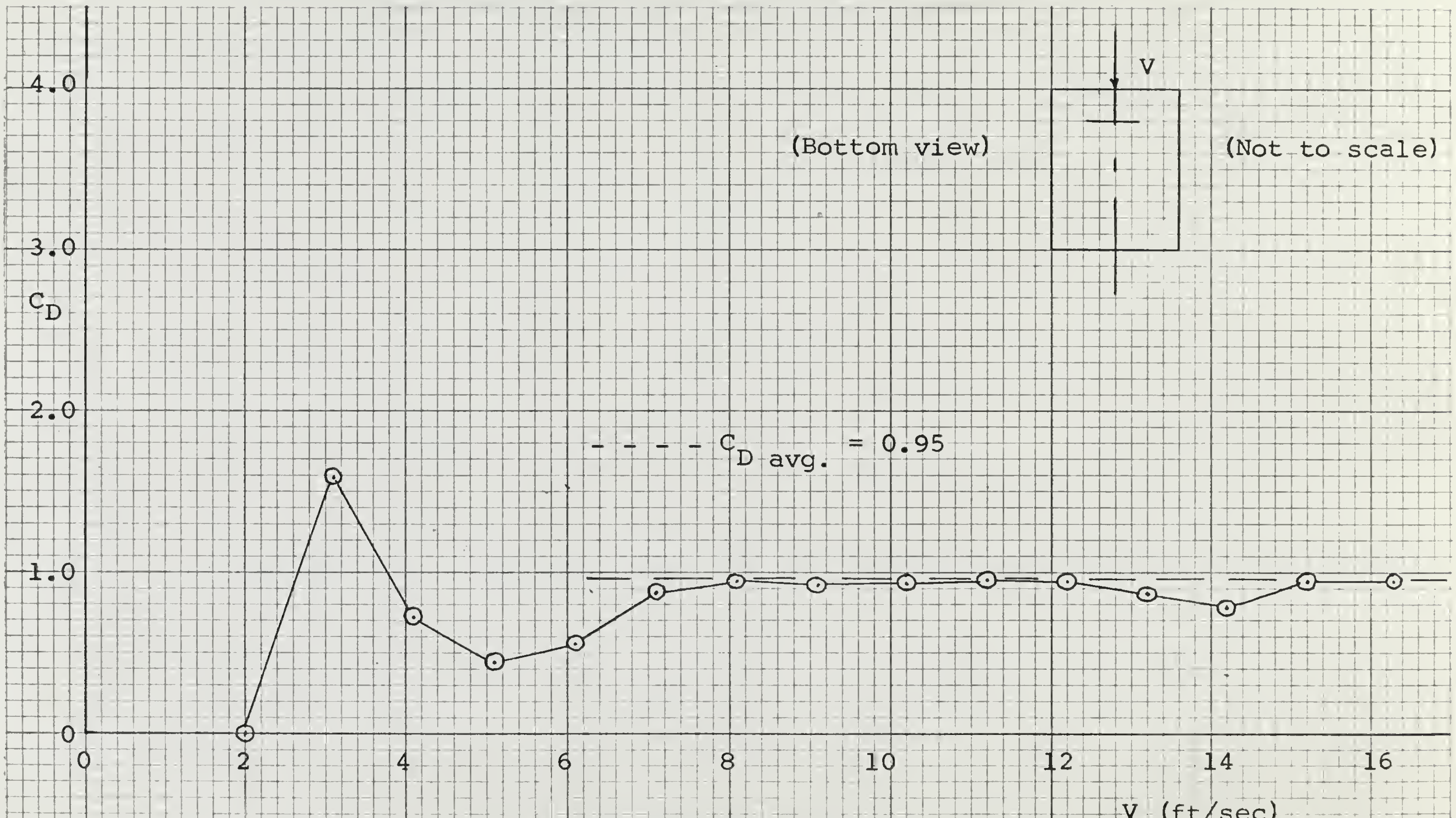


FIGURE 22

NO SPACING ARRAY - 7 PLATELETS C_D

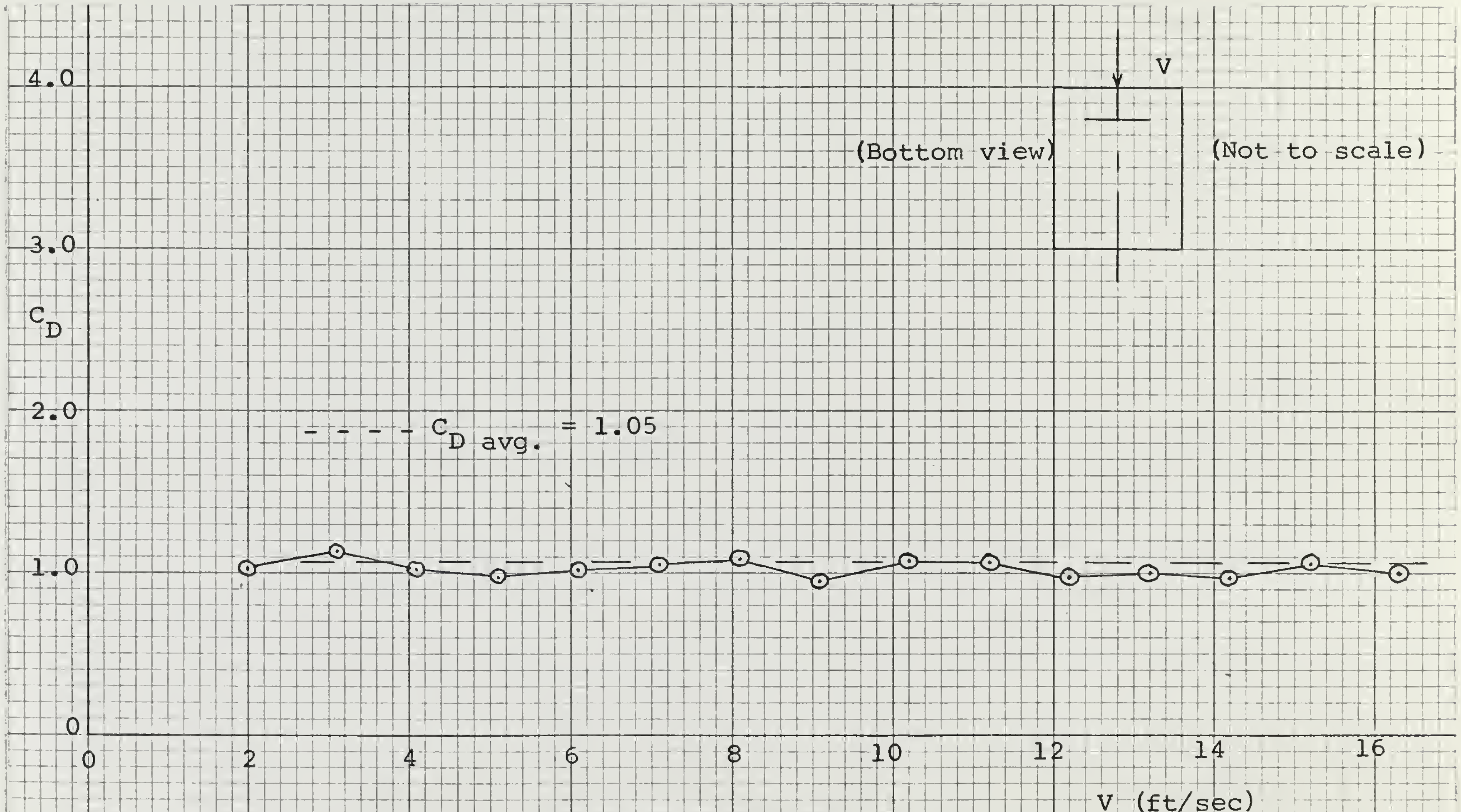
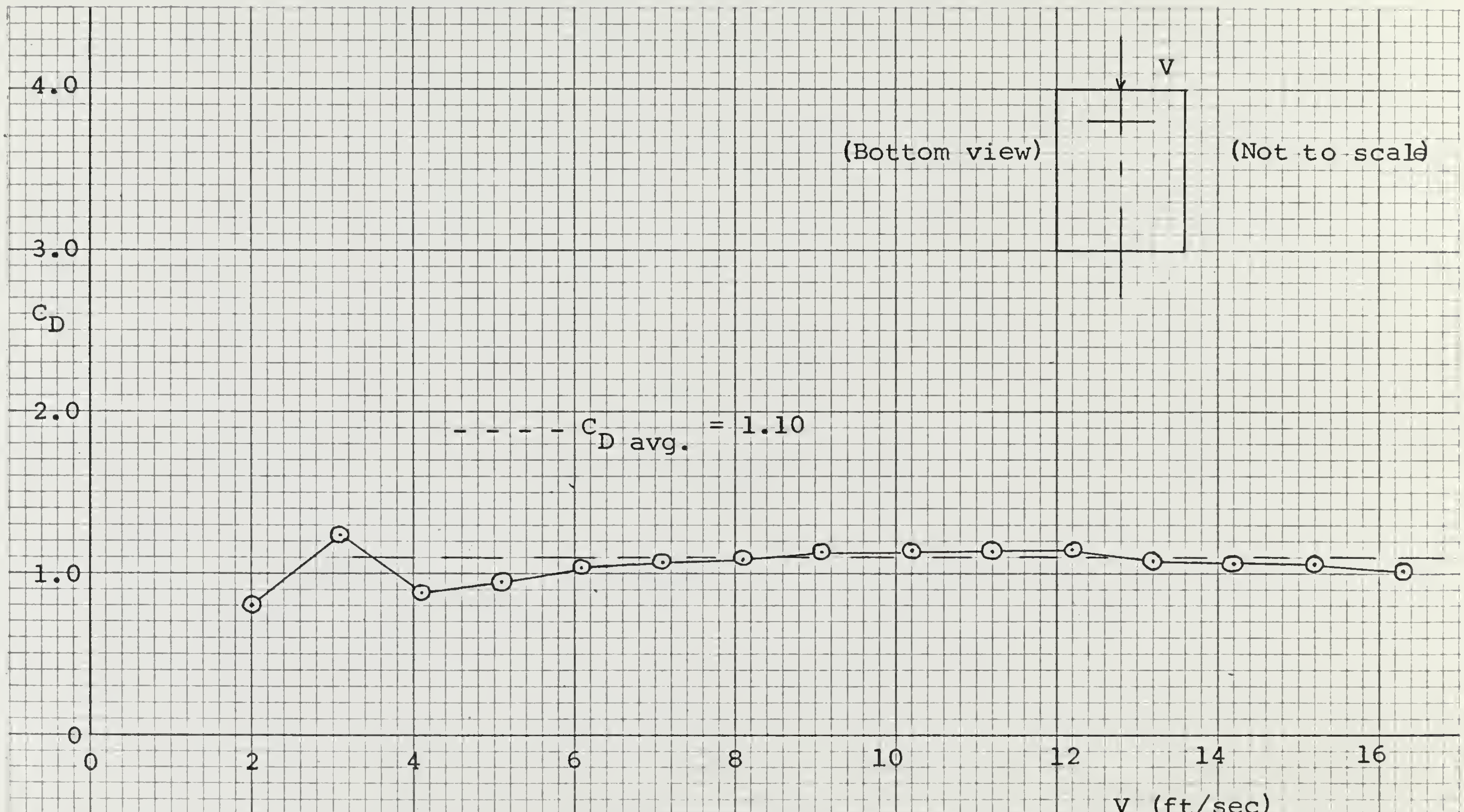


FIGURE 23

NO SPACING ARRAY - 9 PLATELETS C_D



F I G U R E 2 4

NO SPACING ARRAY - 11 PLATELETS C_D

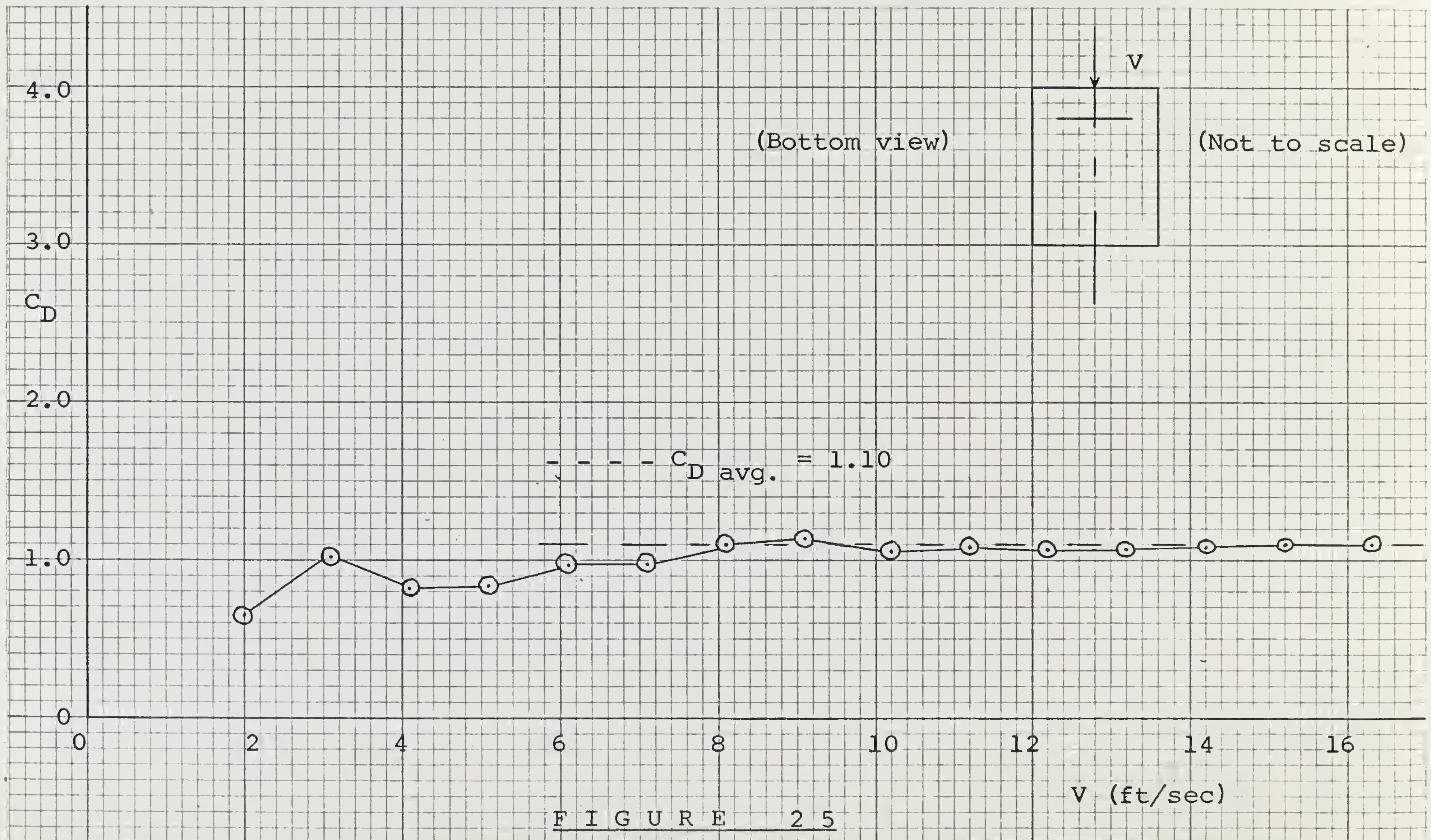


FIGURE 25

NO SPACING ARRAY - 13 PLATELETS C_D

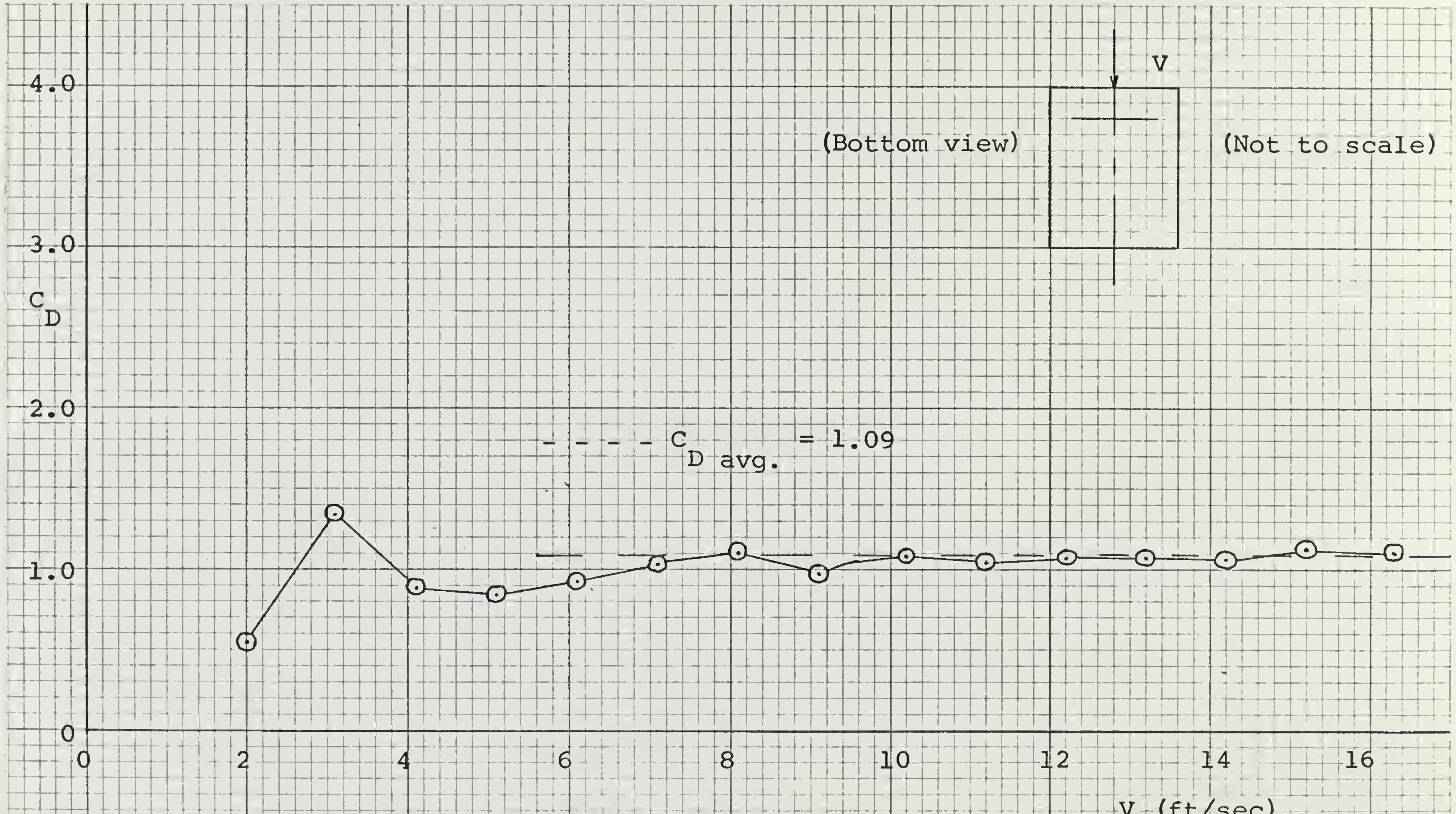


FIGURE 26

NO SPACING ARRAY - 15 PLATELETS C_D

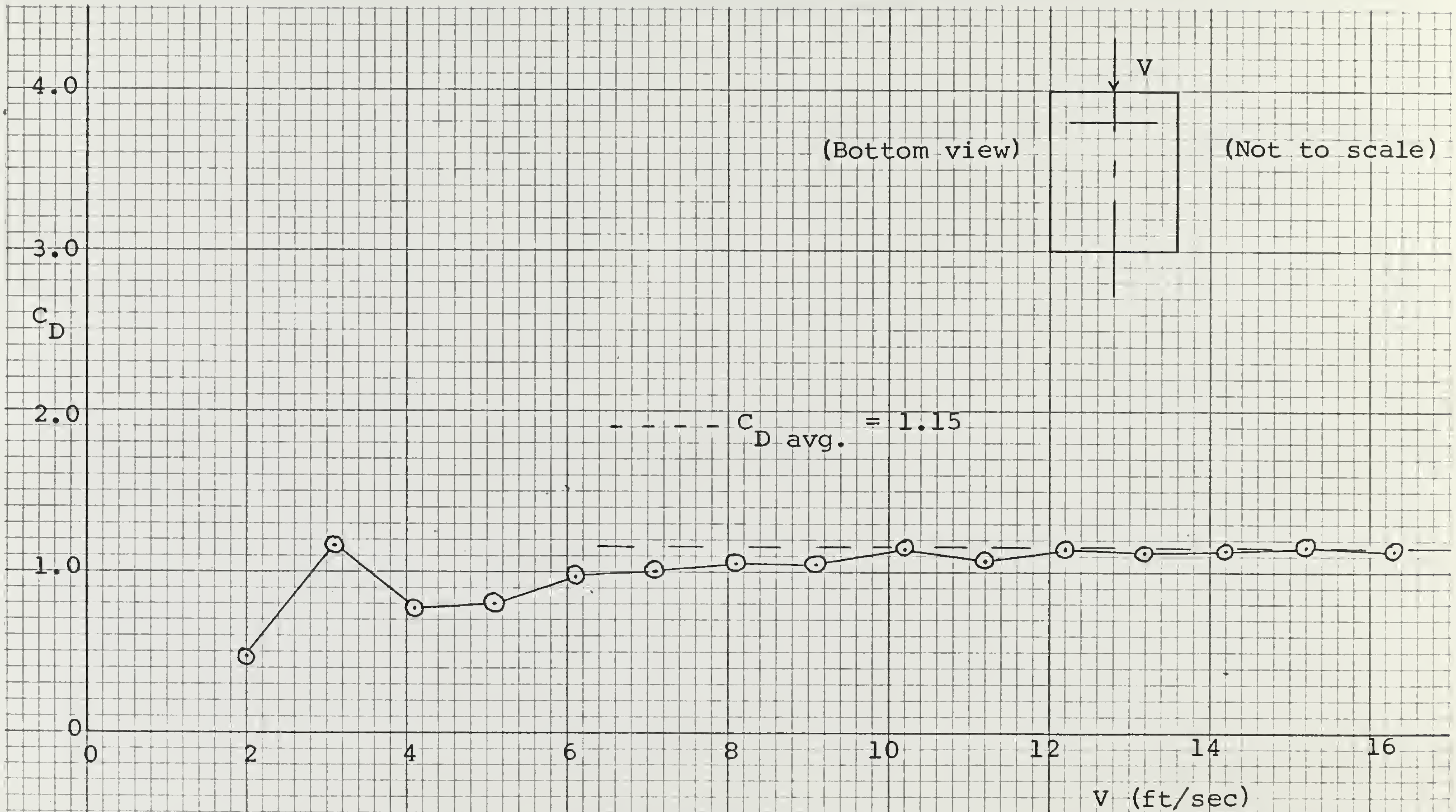


FIGURE 27

NO SPACING ARRAY - 17 PLATELETS C_D

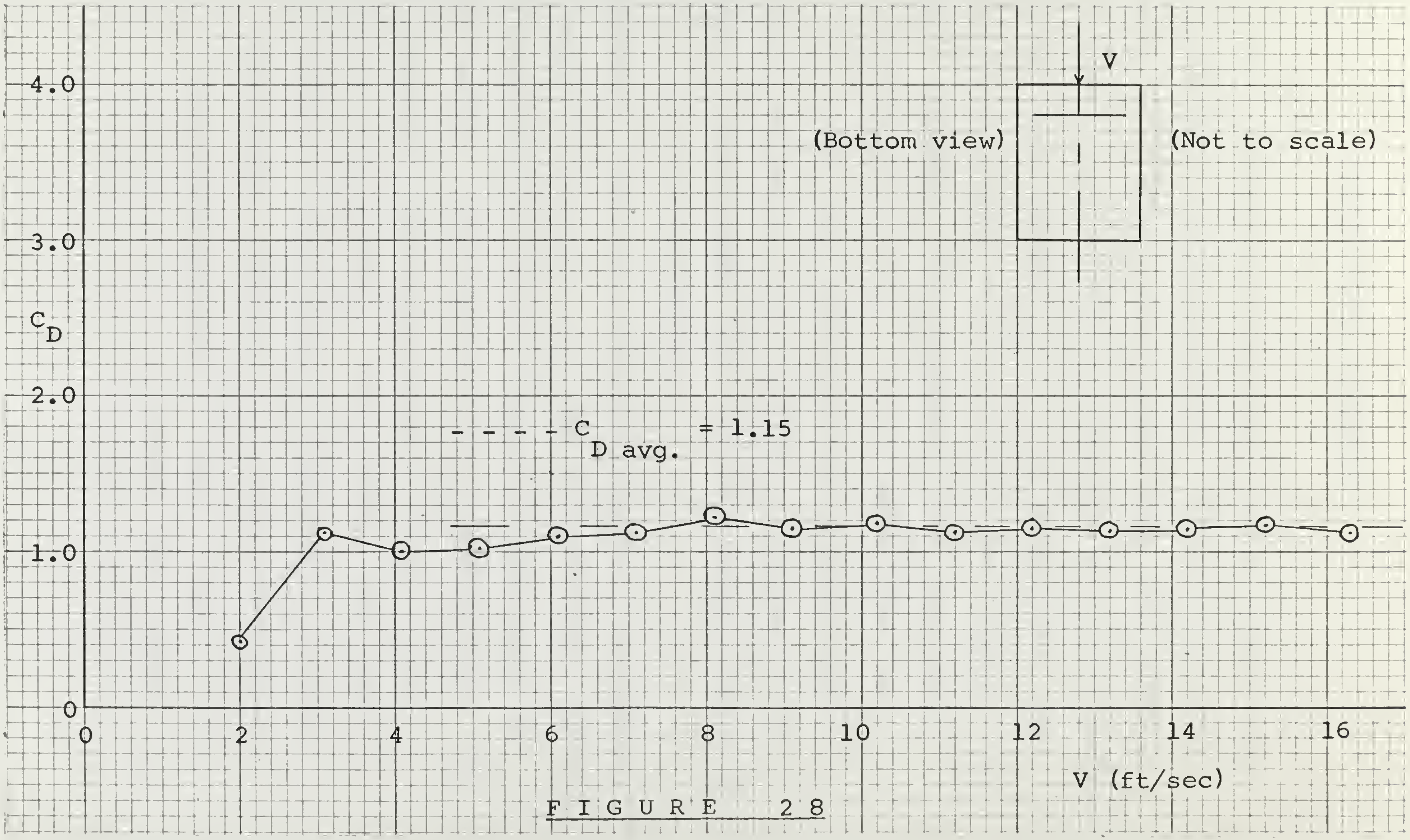


FIGURE 28

DISCUSSION OF RESULTS

Examination of the resulting data from the experimentation reveals several interesting points. Considering just the 1" spacing array alone, it is easily seen from Figure 29 that the coefficient of drag is a maximum at five platelets and that C_D decreases substantially after this point, considering the value plotted at six platelets as slightly high, as is probably the case. This indicates that the value of additional platelets beyond five, i.e., three rows, is marginal. Quite obviously, the drag will increase; but the relative effectiveness of these additional platelets will be small. Hence it would appear that for this array five platelets is the optimum configuration.

Realizing full well from the foregoing that the leading platelets were more effective than the trailing ones, the 1"* array was tested and the results displayed graphically in Figure 29 as before. From this plot it is surmised that the effect of installing additional groups of two platelets, one behind the other, was constant. Thus, little gain could be realized in going to a long group of platelets, one behind the other. This result seemed to put a semi-constraint on the number of transverse platelets to two. At least as far as an optimal configuration was concerned, this seemed to be the case.

Seemingly constrained to five platelets fore and aft and two transversely, the next parameter needing attention was the horizontal (transverse) spacing. (Note: The fore and aft spacing for all arrays was set at 7 inches, so as to provide for both a realistic spacing on the parent ship (42 feet) and an effective basis of comparison of the various arrays.) Thus, the 1 1/4" spacing array was proposed and tested, resulting in the highest coefficient of drag of any array tested (see Figure 29). Although the value of C_D is constant at 1.15 up to and including that for five platelets, it is believed, although not experimentally verified, that the value of C_D for six platelets would be below that of five platelets as was the case in the 1" spacing array.

As a final check on the validity of the results for the above arrays, as well as the determination of the effect of one large platelet, the no spacing array was tested and the results again were plotted in Figure 29. Surprisingly, in no case did the coefficient of drag exceed that of the 1 1/4" spacing array.

From the above it can be stated that for the arrays tested the 1 1/4" spacing design appears to offer the best drag producing ability. It is further felt that if this is not the optimum solution, it is certainly near same. Experimentation done by Hoerner[1] on the interference drag of cylinders and disks in close proximity seems to substantiate

the above conclusion concerning the optimum spacing.

Figure 30 indicates the ability of each configuration in reducing the head reach of a supertanker. Aside from the obvious conclusion that the greater the number of platelets the greater the reduction of head reach, we can detect several other interesting results. For example, a five platelet configuration in the 1 1/4" spacing array is actually more beneficial in terms of reducing head reach than a six platelet configuration in the other arrays. Thus, we can use less platelets and obtain a greater reduction in head reach. Surely, this is the correct direction in which to be headed.

COMPARISON OF C_D'S OF ARRAYS

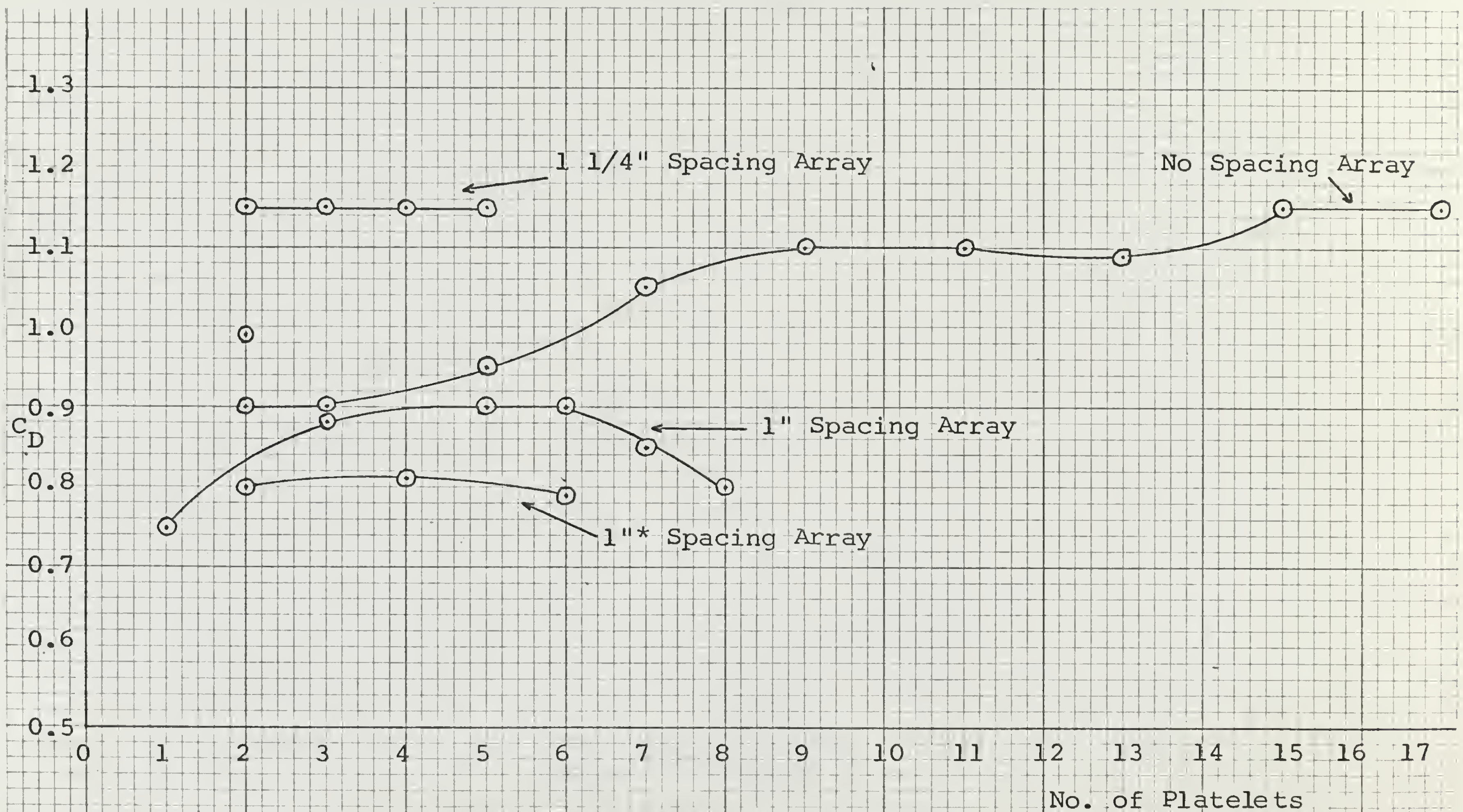
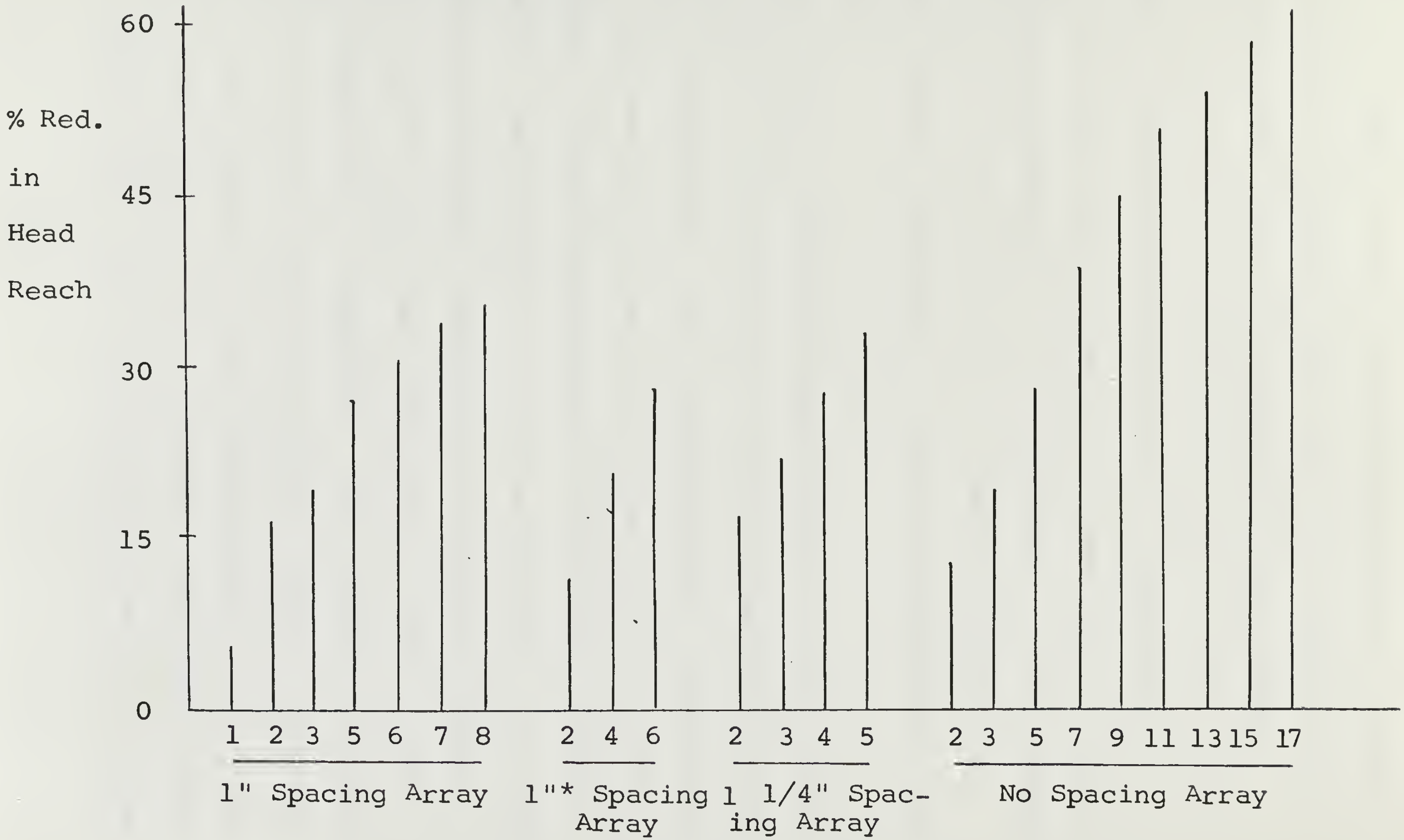


FIGURE 29

PERCENT REDUCTION IN HEAD REACH

VS. NO. OF PLATELETS



F I G U R E 3 0

CONCLUSIONS

From the arrays tested, which evolved from a systematized analysis, it appears that the 1 1/4" spacing array with five platelets offers the optimum or near optimum configuration for use in producing the drag necessary to substantially reduce the head reach of a supertanker. In this case, the head reach is reduced by one-third. Added to this appealing argument for a five platelet, 1 1/4" spacing array is the small size and small number of platelets involved which lends itself well to easy maintenance and high reliability.

At this point, one might wonder whether or not the reduction in head reach offered by the above configuration is sufficient to adequately solve the supertanker deceleration problem. The one-third reduction in head reach coupled with the seemingly increased maneuverability available through the mechanical manipulation of the five platelets, and hence the possible even greater reduction of distance traveled "directly forward" makes the 1 1/4" spacing array - five platelet configuration - appealing. The seventeen platelet configuration of the no spacing array may offer a superior reduction in head reach, but the decreased maneuverability alleged by same, along with its large size and weight, makes it a poor competitor. Thus, it would seem that the optimal

quality of the five platelet configuration of the 1 1/4" spacing array is even more striking upon closer inspection and hence would suffice to adequately solve the ship deceleration problem.

Certainly some degree of pitching of the ship will result from the addition of platelets to the keel. The intensity of the pitching moment was not investigated in this thesis but could be handled rather easily using apparatus and techniques similar to those employed in this manuscript. It is doubtful that the pitching moment developed by the platelets would be constraining; but if this were the case, some additional tradeoffs involving the number of platelets used would have to be made.

Finally, a few words might be said regarding the installation of the platelets to the ship's hull. It is felt by the author that the best method of adapting the platelets to the keel would be to construct a three-sided encasement into which the platelets would be withdrawn when not in use, and cause the platelets to be raised and lowered hydraulically in the normal situation and mechanically in the event of failure of the hydraulic system.

RECOMMENDATIONS

There are only two recommendations which are felt significant. One regards the apparatus and the other, future work in inducing drag forces on supertankers.

First, a load cell of 25 lbf or 50 lbf capacity is sorely needed if accurate results are expected in low speed ranges. Unfortunately, this was not available during this thesis work and hence the values of C_D at low speeds suffered somewhat. Fortunately, however, the main interest of this study was at higher speeds.

Lastly, it is recommended that in further work in platelet arrays, the next step taken be to increase the platelet spacing to 1 1/2" and higher and note the results. It is believed that this is the path to take to confirm optimization.

APPENDIX I

TABLE OF SYMBOLS

A - Total area of platelets normal to flow

Am - Midship area of ship

B - Beam of ship (ft)

C_B - Block Coefficient ($\equiv 35\Delta/LBT$)

C_D - Coefficient of drag based on total area of platelets

C_f - Frictional resistance coefficient

ΔC_f - Correlation factor

C_m - Midship section coefficient ($\equiv Am/BT$)

C_p - Prismatic coefficient ($\equiv \nabla/AmL$)

C_r - Residual resistance coefficient

C_t - Total resistance coefficient

Drag Corr. - Corrected value of drag of platelets

D_L - Lower load cell drag (counts)

D_u - Upper load cell drag (counts)

EHP - Effective horsepower

F_B - Braking force of platelets (lbf)

F_L - Lower load cell force (lbf)

F_R - Ship resistance force (lbf)

F_u - Upper load cell force (lbf)

H - Head reach or distance traveled by ship during deceleration (ft)

L - Length

m - Added mass of ship (lbm)

M - Mass of ship (lbm)

P.C. - Propulsive coefficient ($\equiv$ EHP/SHP)

R - Ship resistance (lbf)

S - Ship wetted surface area (ft^2)

SHP - Shaft horsepower

t - Time (sec)

T - Draft os ship (ft)

V_m - Model speed (ft/sec)

V_p - Ship speed (kts)

x - Distance along plate (in.)

δ - Boundary layer thickness

Δ - Full load displacement of ship (tons)

∇ - Ship volume ($35 \times \Delta$) (ft^3)

ρ - Density

ν - Kinematic viscosity (ft^2/sec)

APPENDIX II

ANALYSIS OF REYNOLDS NUMBER CONSERVATION

Having decided that based on the experiment at hand the Reynolds number was indeed the parameter to conserve, its value was then calculated for the parent ship in the following manner:

$$Re = \frac{V\ L}{\nu}$$

Based on the parent platelet length of 6 feet:

$$Re_p = \frac{V\ (6)}{1.26 \times 10\text{-}5} \times 1.689$$

where V = kts

Hence:

$$\therefore Re_p = 8.04 \times 10^5\ V$$

Now for Reynolds numbers of 10^4 and beyond, as is the case above, the coefficient of drag, C_D, for a plate normal to the flow; i.e., the platelets, is constant over said range. Hence, it then is valid to chose a Reynolds number for the model somewhat less than that of the parent, and still obtain correct results for the coefficient of drag of the model platelets as long as Re is greater than 10^4.

Thus for V_p = 16 kts for example:

$$Re_p = 8.04 \times 10^5\ (16)$$

$$\therefore Re_p = 1.288 \times 10^7$$

Hence chose:

$$Re_m = 1.288 \times 10^5$$

Now:

$$V_m = \frac{Re_m \ (\nu)}{Lm}$$

$$= \frac{Re_m \ (1.055 \times 10^{-5})}{1 \text{ in.} \times \text{ft}/12 \text{ in.}}$$

$$\therefore Vm = \frac{Re_m}{7.9 \times 10^3}$$

Then for Vp = 16 kts:

$$Vm = \frac{1.288 \times 10^5}{7.9 \times 10^3}$$

$$\therefore Vm = 16.30 \text{ ft/sec}$$

In a similar way, a table of model speeds was generated.

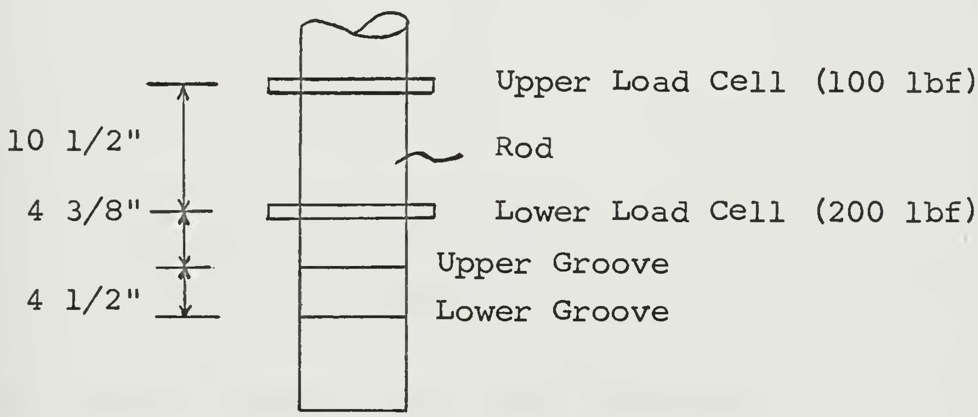
V_p (kts)	Re_p	Re_m	Vm (ft/sec)
2.0	1.61×10^6	1.61×10^4	2.04
3.0	2.42×10^6	2.42×10^4	3.06
4.0	3.22×10^6	3.22×10^4	4.08
5.0	4.02×10^6	4.02×10^4	5.10
6.0	4.83×10^6	4.83×10^4	6.12
7.0	5.63×10^6	5.63×10^4	7.13
8.0	6.44×10^6	6.44×10^4	8.15

V_p (kts)	Re_p	Re_m	Vm (ft/sec)
9.0	7.24×10^6	7.24×10^4	9.16
10.0	8.04×10^6	8.04×10^4	10.18
11.0	8.84×10^6	8.84×10^4	11.20
12.0	9.65×10^6	9.65×10^4	12.20
13.0	1.046×10^7	1.046×10^5	13.22
14.0	1.127×10^7	1.127×10^5	14.25
15.0	1.208×10^7	1.208×10^5	15.28
16.0	1.288×10^7	1.288×10^5	16.30

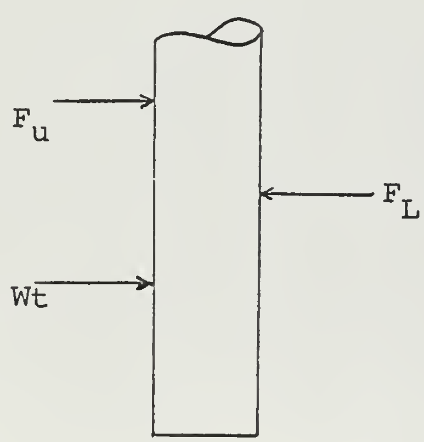
APPENDIX III

DETAILS OF CALIBRATION PROCESS

The calibration of the load cells used to determine the drag force on the plate/platelets was crucial in that a set of simultaneous equations was generated on which all subsequent analyses depended. Pictorially, the situation was as follows:



A horizontal force of known value was applied through use of a weight/pulley system, and the output of the upper and lower load cells recorded. The following resulted:



For the lower groove, the force and moment equations are:

$$\left[\begin{array}{l} F_L = F_u + Wt \\ 10.5\ F_u = 8.875\ Wt \end{array}\right.$$

<u>or</u>

$$(1) \quad \therefore\ F_u = 0.845\ Wt$$

$$(2) \quad \therefore\ F_L = 1.845\ Wt$$

For the upper groove, the force and moment equations are:

$$\left[\begin{array}{l} F_L = F_u + Wt \\ 10.5\ F_u = 4.375\ Wt \end{array}\right.$$

<u>or</u>

$$(3) \quad \therefore\ F_u = 0.417\ Wt$$

$$(4) \quad \therefore\ F_L = 0.417\ Wt$$

Using various weights, the above equations, (1), (2), (3) and (4), were plotted and curves were generated for the conversion of upper and lower load cell outputs in counts to lbf.

APPENDIX IV

PARENT SHIP CHARACTERISTICS

The parent ship chosen to be used in the correlation of experimental data to an existing supertanker was the ESSO PEMBROKESHIRE, which had the following characteristics:

Displacement (Δ) = 101,234 tons

Length (L) = 820 ft.

Beam (B) = 112.5 ft.

Draft (T) = 49.2 ft.

Maximum speed (V_{max}) = 16.4 kts

Shaft horsepower (SHP) = 26,500 HP

Propulsive Coefficient (PC) = 0.65

Midship Section Coefficient (C_m) = 0.99

Proceeding, as dictated by Series 60[16], the value for the total ship resistance coefficient (C_t) was obtained as follows:

$$C_B \equiv \frac{35\,\Delta}{LBT}$$

$$= \frac{35\ (101,234)}{820\ (112.5)\ (49.2)}$$

$$\therefore C_B = 0.78$$

Further:

$$C_p \equiv \frac{\nabla}{AmL} = \frac{C_B}{C_m}$$

where $C_m \equiv Am/BT$

<u>Hence</u>:

$$C_p = \frac{0.78}{0.99}$$

$$\therefore C_p = 0.788$$

<u>Also</u>:

$$L/B = \frac{820}{112.5}$$

$$\therefore L/B = 7.3$$

<u>And</u>:

$$B/T = \frac{112.5}{49.2}$$

$$\therefore B/T = 2.28$$

<u>Now</u>:

$$SHP \sim V^3$$

Hence converting data for 16.4 kts to 16.0 kts:

$$\frac{SHP_{16.0}}{SHP_{16.4}} = \left(\frac{16.0}{16.4}\right)^3$$

$$SHP_{16.0} = 26{,}500\ (0.927)$$

$$\therefore SHP_{16.0} = 24{,}600 \text{ HP}$$

<u>Then</u>:

$$PC \equiv EHP/SHP$$

$$EHP = SHP \cdot PC$$

$$= 24{,}600\ (0.65)$$

$$\therefore \text{EHP} = 16{,}000 \text{ HP}$$

Now, from Table D3 of Series 60 (16):

$$\text{EHP} = \frac{V \cdot R}{325.6}$$

<u>Where</u>:

V = speed of ship in knots

<u>And</u>:

325.6 is a conversion factor used by Series 60 (16)

$$R = \frac{16{,}000\ (325.6)}{16}$$

$$\therefore R = 3.256 \times 10^5 \text{ lbf}$$

Then from Figures B124 and B125 of Series 60 (16):

$$S/\nabla^{2/3} = 6.12$$

$$S = 6.12\ (35 \times 1.01234 \times 10^5)^{2/3}$$

$$\therefore S = 1.425 \times 10^5 \text{ ft}^2$$

<u>Now</u>:

$$C_t \equiv \frac{R}{1/2\ \rho\ V^2\ S}$$

$$= \frac{3.256 \times 10^5}{1/2\ (1.99)\ (27)^2\ (1.425 \times 10^5)}$$

$$\underline{\underline{\therefore C_t = 3.15 \times 10^{-3} \quad \text{for } V_p = 16 \text{ kts}}}$$

APPENDIX V

DEVELOPMENT OF HEAD REACH EQUATION

The equation for the head reach attained during the deceleration of a ship from a given initial speed to a given final speed is enumerated below. The only assumption made is that the added mass of the ship, m, is equal to 5 percent of the total mass of the ship. This assumption is taken from Van Manen.[14]

$$F = M^* \frac{dV}{dt}$$

where $M^* = m + M$

But:

$$m = 0.05M$$

Hence:

$$F = 1.05M \frac{dV}{dt}$$

Now:

Total force = hull resistance + resistance offered by the brake

$$\therefore F \equiv F_R + F_B$$

where

$$F_R \equiv C_t \, 1/2 \, \rho \, V^2 \, S$$

$$F_B \equiv C_D \, 1/2 \, \rho \, V^2 \, A$$

And:

Total		Frictional		Residual		Correlation
Resistance	=	Resistance	+	Resistance	+	Factor
Coeff.		Coeff.		Coeff.		

$$\therefore C_t = C_f + C_r + \Delta C_f$$

the frictional resistance being derived from the hull and the residual resistance from the wave motions.

Then:

$$F_R + F_B = 1.05\ M\ \frac{dV}{dt}$$

$$1/2\ \rho\ V^2\ (C_t\ S + C_D\ A) = 1.05\ M\ \frac{dV}{dt}$$

Now:

$$\frac{dV}{dt} = \frac{dV}{dH} \cdot \frac{dH}{dt}$$

$$\therefore \frac{dV}{dt} = V\ \frac{dV}{dH}$$

where $H \equiv$ head reach

Hence:

$$1/2\ \rho\ V^2\ (C_t\ S + C_D\ A) = 1.05\ M\ V\ \frac{dV}{dH}$$

$$1/2\ \rho\ V\ (C_t\ S + C_D\ A) = 1.05\ M\ \frac{dV}{dH}$$

Rearranging the above equation:

$$\frac{dV}{V} = \frac{\rho}{2.1\ M}\ (C_t\ S + C_D\ A)\ dH$$

Realizing that C_D is independent of time as discussed in the "Results" section of this manuscript and assuming for the moment that C_t is also independent of time, we obtain upon integration of both sides of the above equation:

$$(\ln V)_{V_o}^{V_f} = \frac{\rho}{2.1\ M} \quad (C_t\ S + C_D\ A) \quad (H)_{H_o}^{H_f}$$

Note: C_t is not strictly independent of time and hence its effect will be handled numerically later in this section.

$$\ln V_f - \ln V_o = \frac{\rho}{2.1\ M} \quad (C_t\ S + C_D\ A) \quad (H_f - H_o)$$

Now:

$$@\ t = o \quad , \quad V_o = 16 \text{ kts or } 27 \text{ ft/sec}$$

Hence:

$$\ln V_f - \ln (27) = \frac{\rho}{2.1\ M} \quad (C_t\ S + C_D\ A) \quad (H_f - H_o)$$

But:

$$H_f - H_o = -H$$

Thus:

$$\ln V_f - 3.3 = \frac{-\rho}{2.1\ M} \quad (C_t\ S + C_D\ A) \quad (H)$$

$$\therefore \quad H = \frac{2.1\ M\ (3.3 - \ln V_f)}{\rho\ (C_t\ S + C_D\ A)}$$

But:

$$M = \triangle \times 2240 \quad \text{lbm}$$

And:

ρ = 64 lbm/ft^3

Thus:

$$(5) \quad \therefore H = \frac{2.1\ (\Delta)\ (2240)\ (3.3 - \ln V_f)}{64\ \ (C_t\ S + C_D\ A)}$$

Up until this point the parameter, C_t, has been neglected but with good reason. Having consulted Baba's article(17), a graph of C_t vs. speed was obtained and later confirmed for data of the parent ship chosen in Appendix IV; i.e., ESSO PEMBROKESHIRE. However, the variation of C_t with speed was of a nature as to preclude evaluation in equation (5) by methods other than numerical (see Figure 31). Hence the procedure followed for the speed range of sixteen to six knots was:

From equation (5) for V = 16 to 15 kts:

$$H = \frac{2.1\ \Delta\ (2240)\ (3.3 - \ln\ (15 \times 1.689))}{64\ \ (C_t\ S + C_D\ A)}$$

$$= \frac{2.1\ \ (101,234)\ \ (2240)\ \ (3.3 - 3.23)}{64\ ((3.15 \times 10^{-3})\ \ (1.425 \times 10^5) + C_D\ A)}$$

$$(6) \quad \therefore H = \frac{5.21 \times 10^5}{4.49 \times 10^2 + C_D\ A}$$

For V = 15 to 14 kts:

$$H = \frac{2.1\ (101,234)(2240)\ \ (3.23 - \ln(14 \times 1.689))}{64\ ((3.06 \times 10^{-3})\ (1.425 \times 10^5) + C_D\ A)}$$

$$(7) \quad \therefore H = \frac{5.21 \times 10^5}{4.36 \times 10^2 + C_D\ A}$$

For V = 14 to 13 kts:

$$H = \frac{2.1\ (101,234)(2240)\ \ (3.16 - \ln(13 \times 1.689))}{64\ ((3.03 \times 10^{-3})\ (1.425 \times 10^5) + C_D\ A)}$$

VARIATION OF C_t WITH SPEED FOR SUPERTANKERS

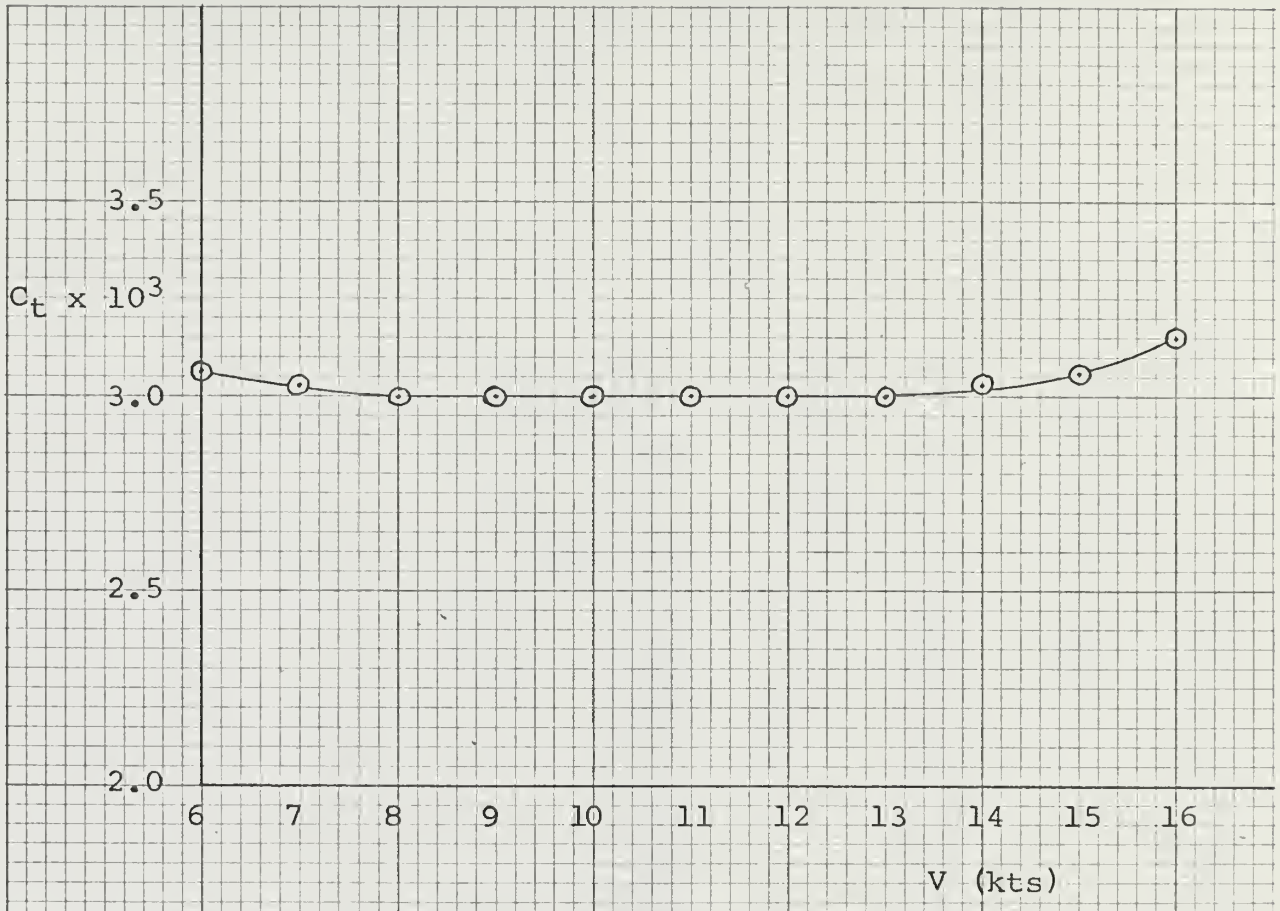


FIGURE 31

$$(8) \quad \therefore \dot{H} = \frac{5.21 \times 10^5}{4.32 \times 10^2 + C_D A}$$

<u>For V = 13 to 8 kts</u>:

$$\dot{H} = \frac{2.1 \ (101,234)(2240 \ (3.09 - \ln(8 \times 1.689))}{64 \ ((3.0 \times 10^{-3})(1.425 \times 10^5) + C_D A)}$$

$$(9) \quad \therefore \dot{H} = \frac{3.65 \times 10^6}{4.275 \times 10^2 + C_D A}$$

<u>For V = 8 to 7 kts</u>:

$$\dot{H} = \frac{2.1 \ (101,234)(2240)(2.06 - \ln(7 \times 1.689))}{64 \ ((3.03 \times 10^{-3})(1.425 \times 10^5) + C_D A)}$$

$$(10) \quad \therefore \dot{H} = \frac{9.65 \times 10^5}{4.32 \times 10^2 + C_D A}$$

<u>For V = 7 to 6 kts</u>:

$$\dot{H} = \frac{2.1 \ (101,234)(2240)(2.47 - \ln(6 \times 1.689))}{64 \ ((3.06 \times 10^{-3})(1.425 \times 10^5) + C_D A)}$$

$$(11) \quad \therefore \dot{H} = \frac{1.118 \times 10^6}{4.36 \times 10^2 + C_D A}$$

APPENDIX VI

SAMPLE CALCULATIONS

The following is a calculation of the head reach attained by a supertanker with and without a braking device. In this example, the 1 1/4" spacing array consisting of five platelets was chosen for analysis. Initially, from Figure 19, the average coefficient of drag was obtained for this configuration.

Hence:

$$C_{D\ avg.} = 1.15$$

Now from equation (6) without braking device for V = 16 to 15 kts:

$$H = \frac{5.21 \times 10^5}{4.49 \times 10^2}$$

$$\text{(a)} \quad \therefore H = 1{,}160 \text{ ft.}$$

From equation (7) without braking device for V = 15 to 14 kts:

$$H = \frac{5.21 \times 10^5}{4.36 \times 10^2}$$

$$\text{(b)} \quad \therefore H = 1{,}195 \text{ ft.}$$

From equation (8) without braking device for V = 14 to 13 kts:

$$H = \frac{5.21 \times 10^5}{4.32 \times 10^2}$$

$$\text{(c)} \quad \therefore H = 1{,}205 \text{ ft.}$$

From equation (9) without braking device for V = 13 to 8 kts:

$$H = \frac{3.65 \times 10^6}{4.275 \times 10^2}$$

$$\text{(d)} \quad \therefore H = 8{,}530 \text{ ft.}$$

From equation (10) without braking device for V = 8 to 7 kts:

$$H = \frac{9.65 \times 10^5}{4.32 \times 10^2}$$

$$\text{(e)} \quad \therefore H = 2{,}238 \text{ ft.}$$

From equation (11) without braking device for V = 7 to 6 kts:

$$H = \frac{1.118 \times 10^6}{4.36 \times 10^2}$$

$$\text{(f)} \quad \therefore H = 2{,}560 \text{ ft.}$$

Adding equations (a) through (f):

$$\underline{\underline{\therefore H = 16{,}888 \text{ ft.}}}$$

Note: Area of each parent platelet equals 36 $ft.^2$.

Now from equation (6) with the five platelet brake for V = 16 to 15 kts:

$$H = \frac{5.21 \times 10^5}{4.49 \times 10^2 + C_D A}$$

$$= \frac{5.21 \times 10^5}{4.49 \times 10^2 + 1.15 (5 \times 36)}$$

$$\text{(a')} \quad \therefore H = 784 \text{ ft.}$$

From equation (7) with the five platelet brake for V = 15 to 14 kts:

$$H = \frac{5.21 \times 10^5}{4.36 \times 10^2 + C_D A}$$

$$= \frac{5.21 \times 10^5}{4.36 \times 10^2 + 1.15 (5 \times 36)}$$

(b') $\therefore H = 810$ ft.

From equation (8) with the five platelet brake for V = 14 to 13 kts:

$$H = \frac{5.21 \times 10^5}{4.32 \times 10^2 + C_D A}$$

$$= \frac{5.21 \times 10^5}{4.32 \times 10^2 + 1.15 (5 \times 36)}$$

(c') $\therefore H = 815$ ft.

From equation (9) with the five platelet brake for V = 13 to 8 kts:

$$H \doteq \frac{3.65 \times 10^6}{4.275 \times 10^2 + C_D A}$$

$$= \frac{3.65 \times 10^6}{4.275 \times 10^2 + 1.15 (5 \times 36)}$$

(d') $\therefore H = 5{,}760$ ft.

From equation (10) with the five platelet brake for V = 8 to 7 kts:

$$H = \frac{9.65 \times 10^5}{4.32 \times 10^2 + C_D A}$$

$$= \frac{9.65 \times 10^5}{4.32 \times 10^2 + 1.15 (5 \times 36)}$$

(e') $\therefore H = 1{,}510$ ft.

From equation (11) with the five platelet brake for V = 7 to 6 kts:

$$H = \frac{1.118 \times 10^6}{4.36 \times 10^2 + C_D A}$$

$$= \frac{1.118 \times 10^6}{4.36 \times 10^2 + 1.15 (5 \times 36)}$$

$$(f') \quad \therefore H = 1,735 \text{ ft.}$$

Adding equations (a') through (f'):

$$\underline{\underline{\therefore H = 11,414 \text{ ft.}}}$$

<u>Hence</u>:

$$\text{\% reduction in head reach by addition of platelets} = \frac{16,888 - 11,414}{16,888} \times 100$$

$$\underline{\underline{\therefore \% = 32.4\%}}$$

APPENDIX VII

SUMMARY OF CALCULATIONS

1" Spacing Array

No. of Platelets	C_D	Head Reach Without Brake (ft)	Head Reach With Brake (ft)	% Reduction in Head Reach
1	0.75	16,888	15,940	5.6
2	0.99	16,888	14,493	16.5
3	0.88	16,888	13,866	17.9
5	0.90	16,888	12,301	27.2
6	0.90	16,888	11,645	31.0
7	0.85	16,888	11,286	33.2
8	0.80	16,888	11,044	34.6

1"* Spacing Array

No. of Platelets	C_D	Head Reach Without Brake (ft)	Head Reach With Brake (ft)	% Reduction in Head Reach
2	0.80	16,888	14,926	11.6
4	0.81	16,888	13,289	21.3
6	0.79	16,888	12,106	28.3

1 1/4" Spacing Array

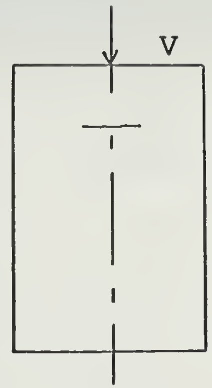
No. of Platelets	C_D	Head Reach Without Brake (ft)	Head Reach With Brake (ft)	% Reduction in Head Reach
2	1.15	16,888	14,165	16.1
3	1.15	16,888	13,154	22.1
4	1.15	16,888	12,207	27.7
5	1.15	16,888	11,414	32.4

No Spacing Array

No. of Platelets	C_D	Head Reach Without Brake (ft)	Head Reach With Brake (ft)	% Reduction in Head Reach
2	0.90	16,888	14,675	13.1
3	0.90	16,888	13,786	18.4
5	0.95	16,888	12,103	28.3
7	1.05	16,888	10,466	38.0
9	1.10	16,888	9,247	45.2
11	1.10	16,888	8,407	50.2
13	1.09	16,888	7,743	54.2
15	1.15	16,888	6,928	58.9
17	1.15	16,888	6,415	62.0

1" SPACING ARRAY - 1 PLATELET

(Bottom view)



(Not to scale)

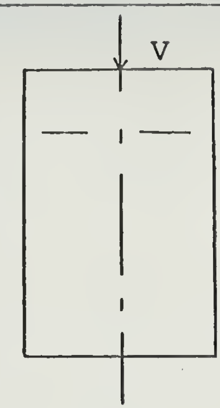
V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	$F_L - F_u$ (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	3.0	0.5	1.0	0.5	0.0	0.00
3.0	3.06	3.0	6.0	1.0	1.7	0.7	0.0	0.00
4.0	4.08	5.0	11.5	1.2	3.0	1.8	0.0	0.00
5.0	5.10	8.0	18.5	1.6	4.8	3.2	0.1	0.57
6.0	6.12	15.0	28.0	2.8	7.2	4.4	0.1	0.39
7.0	7.13	20.5	38.5	3.7	9.7	6.0	0.0	0.00
8.0	8.15	26.0	51.0	4.6	13.0	8.4	0.2	0.45
9.0	9.16	31.0	63.5	5.5	16.0	10.5	0.2	0.35
10.0	10.18	38.0	80.0	6.6	20.1	13.5	0.5	0.72

1" SPACING ARRAY - 1 PLATELET

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	$F_L - F_u$ (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	45.0	95.5	7.8	24.0	16.2	0.6	0.71
12.0	12.20	53.5	113.5	9.2	28.3	19.1	0.5	0.50
13.0	13.22	63.0	132.0	10.7	33.0	22.3	0.8	0.68
14.0	14.25	73.5	155.0	12.5	38.6	26.1	1.1	0.81
15.0	15.28	83.5	176.0	14.0	43.9	29.9	1.2	0.77
16.0	16.30	91.0	192.5	15.3	48.0	32.7	1.3	0.75

1" SPACING ARRAY - 2 PLATELETS

(Bottom view)



(Not to scale)

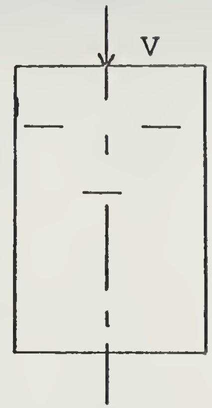
V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	2.5	3.0	0.8	1.0	0.2	0.0	0.00
3.0	3.06	3.0	6.5	1.0	1.5	0.5	0.0	0.00
4.0	4.08	5.0	12.0	1.2	3.2	2.0	0.0	0.00
5.0	5.10	7.5	18.5	1.6	4.8	3.2	0.1	0.28
6.0	6.12	12.0	26.5	2.4	6.8	4.4	0.1	0.19
7.0	7.13	15.0	35.5	2.9	9.0	6.1	0.4	0.59
8.0	8.15	17.5	47.0	3.2	12.0	8.8	0.7	0.79
9.0	9.16	23.5	61.0	4.2	15.5	11.3	1.2	1.06
10.0	10.18	32.0	79.0	5.6	19.9	14.3	1.7	1.22

1" SPACING ARRAY - 2 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	45.0	98.0	7.7	24.5	16.8	1.7	1.01
12.0	12.20	57.5	119.0	9.7	29.7	20.0	2.0	0.99
13.0	13.22	73.5	141.0	12.5	35.2	22.7	2.3	0.98
14.0	14.25	86.0	166.0	14.5	41.4	26.9	2.7	0.99
15.0	15.28	100.0	192.5	16.9	48.0	31.1	3.3	1.05
16.0	16.30	109.0	210.0	18.2	52.2	34.0	3.3	0.96

<u>1" SPACING ARRAY - 3 PLATELETS</u>

(Bottom view)



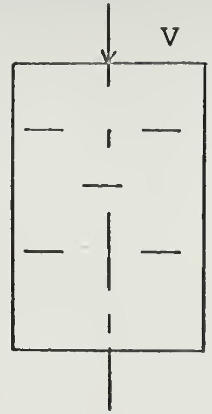
(Not to scale)

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	3.0	0.5	1.0	0.5	0.0	0.00
3.0	3.06	2.5	6.5	0.9	1.8	0.9	0.0	0.00
4.0	4.08	4.5	12.0	1.2	3.2	2.0	0.0	0.00
5.0	5.10	6.5	18.5	1.5	4.8	3.3	0.2	0.38
6.0	6.12	10.5	26.5	2.0	6.8	4.8	0.5	0.66
7.0	7.13	13.5	36.0	2.6	9.1	6.5	0.8	0.78
8.0	8.15	17.5	49.5	3.3	12.5	9.2	1.1	0.82
9.0	9.16	25.5	63.5	4.6	16.0	11.4	1.3	0.77
10.0	10.18	36.0	83.5	6.3	21.0	14.7	2.1	1.01

1" SPACING ARRAY - 3 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	$F_L - F_u$ (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	47.0	101.0	8.0	25.3	17.3	2.2	0.87
12.0	12.20	61.0	123.0	10.5	30.7	20.2	2.2	0.73
13.0	13.22	79.0	148.0	13.4	37.0	23.6	3.2	0.91
14.0	14.25	92.0	173.0	15.5	43.0	27.5	3.3	0.81
15.0	15.28	106.0	199.0	17.7	49.5	31.8	4.0	0.85
16.0	16.30	114.5	217.0	19.2	54.0	34.8	4.1	0.79

1" SPACING ARRAY - 5 PLATELETS

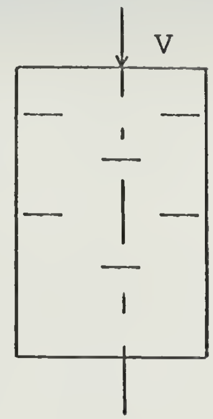
(Bottom view)  (Not to scale)

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	3.5	0.5	1.2	0.7	0.2	1.43
3.0	3.06	3.0	7.0	1.0	2.0	1.0	0.1	0.32
4.0	4.08	5.0	13.5	1.3	3.6	2.3	0.3	0.54
5.0	5.10	7.5	21.0	2.1	5.5	3.4	0.3	0.34
6.0	6.12	11.5	29.0	2.3	7.5	5.2	0.9	0.72
7.0	7.13	15.0	40.5	2.8	10.3	7.5	1.8	1.06
8.0	8.15	19.5	54.0	3.5	13.6	10.1	2.0	0.90
9.0	9.16	27.5	70.5	4.9	17.7	12.8	2.7	0.96
10.0	10.18	38.0	90.0	6.6	22.5	15.9	3.3	0.95

1" SPACING ARRAY - 5 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	41.0	106.5	7.1	26.6	19.5	4.4	1.05
12.0	12.20	58.5	129.0	10.0	32.2	22.2	4.2	0.84
13.0	13.22	71.5	152.5	12.2	38.0	25.8	5.4	0.92
14.0	14.25	92.5	184.5	15.5	45.8	30.3	6.1	0.89
15.0	15.28	107.5	212.0	18.0	52.7	34.7	6.9	0.88
16.0	16.30	117.0	232.0	19.5	57.7	38.2	7.5	0.86

1" SPACING ARRAY - 6 PLATELETS

(Bottom view)  (Not to scale)

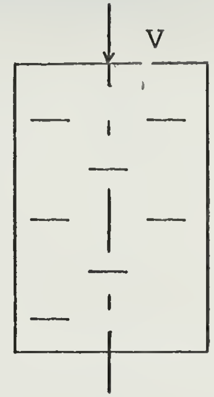
V_p (Kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	3.5	0.5	1.2	0.7	0.2	1.19
3.0	3.06	3.0	8.0	1.0	2.2	1.2	0.3	0.80
4.0	4.08	5.0	13.5	1.2	3.6	2.4	0.4	0.60
5.0	5.10	7.5	21.5	1.6	5.5	3.9	0.8	0.76
6.0	6.12	11.0	30.0	2.2	7.7	5.5	1.2	0.79
7.0	7.13	15.5	41.0	3.0	10.5	7.5	1.8	0.89
8.0	8.15	21.0	55.0	3.8	14.0	10.2	2.1	0.78
9.0	9.16	27.0	71.0	4.7	18.0	13.3	3.2	0.95
10.0	10.18	37.0	91.0	6.5	22.9	16.4	3.8	0.91

1" SPACING ARRAY - 6 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
10.0	10.18	37.0	91.0	6.5	22.9	16.4	3.8	0.91
11.0	11.20	41.0	108.0	7.1	27.0	19.9	4.8	0.95
12.0	12.20	57.5	131.5	9.7	32.8	23.1	5.1	0.85
13.0	13.22	71.0	156.0	12.0	39.0	27.0	6.6	0.94
14.0	14.25	96.0	190.0	16.0	47.4	31.4	7.2	0.88
15.0	15.28	109.0	218.5	18.2	54.4	36.2	8.4	0.89
16.0	16.30	119.0	237.0	20.0	59.0	39.0	8.3	0.80

1" SPACING ARRAY - 7 PLATELETS

(Bottom view)



(Not to scale)

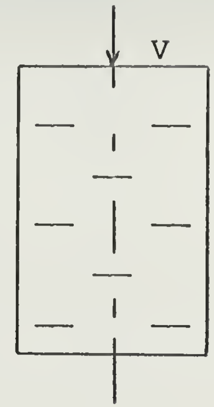
V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	3.0	0.5	1.0	0.5	0.0	0.00
3.0	3.06	2.5	8.0	0.8	2.3	1.5	0.6	1.36
4.0	4.08	5.0	13.5	1.2	3.7	2.5	0.5	0.64
5.0	5.10	7.5	22.0	1.6	5.7	4.1	1.0	0.82
6.0	6.12	11.0	31.0	2.2	8.0	5.8	1.5	0.85
7.0	7.13	18.5	44.0	3.5	11.2	7.7	2.0	0.84
8.0	8.15	25.0	59.0	4.5	15.0	10.5	2.4	0.77
9.0	9.16	27.0	72.0	4.8	18.0	13.2	3.1	0.79
10.0	10.18	33.5	92.0	5.9	23.0	17.1	4.5	0.93

1" SPACING ARRAY - 7 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	43.5	110.0	7.5	27.5	20.0	4.9	0.83
12.0	12.20	56.0	134.0	9.5	33.5	24.0	6.0	0.86
13.0	13.22	70.0	157.0	12.0	39.0	27.0	6.6	0.80
14.0	14.25	95.5	194.0	16.0	48.3	32.3	8.1	0.85
15.0	15.28	108.5	219.0	18.2	54.5	36.3	8.5	0.83
16.0	16.30	118.0	240.0	19.7	59.5	39.8	9.1	0.75

1" SPACING ARRAY - 8 PLATELETS

(Bottom view)



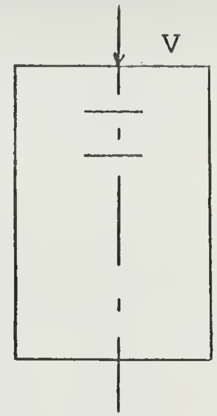
(Not to scale)

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	$F_L - F_u$ (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	2.5	3.0	0.8	1.0	0.2	0.0	0.00
3.0	3.06	4.0	8.5	1.0	2.3	1.3	0.4	0.79
4.0	4.08	6.0	14.5	1.5	3.8	2.3	0.3	0.34
5.0	5.10	10.5	23.0	2.1	6.0	3.9	0.8	0.57
6.0	6.12	14.0	32.0	2.7	8.2	5.5	1.2	0.59
7.0	7.13	17.5	43.5	3.3	11.0	7.7	2.0	0.73
8.0	8.15	24.5	59.5	4.5	15.0	10.5	2.4	0.67
9.0	9.16	32.0	77.0	5.6	19.4	13.8	3.7	0.82
10.0	10.18	52.0	104.0	9.0	26.0	17.0	4.4	0.79

1" SPACING ARRAY - 8 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	65.0	126.0	11.0	31.5	20.5	5.4	0.80
12.0	12.20	82.5	151.0	14.0	37.6	23.6	5.6	0.70
13.0	13.22	94.0	175.5	15.8	43.7	27.9	7.5	0.79
14.0	14.25	117.5	211.0	19.5	52.5	33.0	8.8	0.81
15.0	15.28	136.5	241.0	22.7	60.0	37.3	9.5	0.76
16.0	16.30	146.0	265.0	24.4	66.0	41.6	10.9	0.79

1"* SPACING ARRAY - 2 PLATELETS

(Bottom view)  (Not to scale)

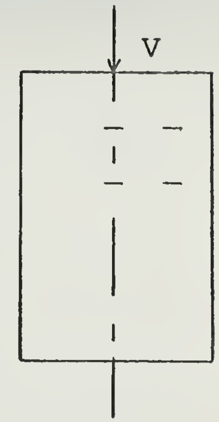
V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	$F_L - F_u$ (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	3.0	0.5	1.0	0.5	0.0	0.00
3.0	3.06	2.5	7.0	0.8	2.0	1.2	0.3	2.38
4.0	4.08	6.0	12.0	1.5	4.2	2.7	0.8	3.56
5.0	5.10	10.5	21.0	2.1	5.5	3.4	0.3	0.86
6.0	6.12	16.5	30.5	3.0	7.8	4.8	0.5	0.99
7.0	7.13	25.5	42.0	4.5	10.6	6.1	0.0	0.00
8.0	8.15	30.0	55.0	5.4	14.0	8.6	0.4	0.45
9.0	9.16	35.5	68.0	6.2	17.1	10.9	0.6	0.53
10.0	10.18	41.0	85.5	7.1	21.5	14.4	1.4	1.01

1"* SPACING ARRAY - 2 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	49.0	101.0	8.5	25.3	16.8	1.2	0.71
12.0	12.20	57.5	119.5	9.7	29.9	20.2	1.6	0.80
13.0	13.22	68.0	139.0	11.5	34.6	23.1	1.6	0.68
14.0	14.25	76.0	161.5	12.9	40.2	27.3	2.3	0.84
15.0	15.28	87.0	183.5	14.6	45.7	31.1	2.4	0.77
16.0	16.30	95.0	202.0	16.0	50.3	34.3	2.9	0.84

1"* SPACING ARRAY - 4 PLATELETS

(Bottom view)



(Not to scale)

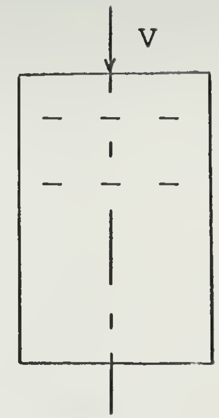
V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	3.0	0.5	1.0	0.5	0.0	0.00
3.0	3.06	2.5	7.0	0.8	2.0	1.2	0.3	1.20
4.0	4.08	5.0	13.0	1.2	3.5	2.3	0.4	0.89
5.0	5.10	10.0	21.0	2.0	5.5	3.5	0.4	0.57
6.0	6.12	17.0	32.5	3.2	8.3	5.1	0.8	0.40
7.0	7.13	25.0	45.0	4.5	11.5	7.0	1.1	0.81
8.0	8.15	30.5	58.0	5.4	14.6	9.2	1.0	0.56
9.0	9.16	35.5	72.5	6.3	18.3	12.0	1.7	0.75
10.0	10.18	42.0	90.0	7.3	22.5	15.2	2.2	0.79

1"* SPACING ARRAY - 4 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	$F_L - F_u$ (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	49.5	107.0	8.5	26.8	18.3	2.7	0.80
12.0	12.20	57.0	126.0	9.7	31.5	21.8	3.2	0.80
13.0	13.22	67.0	146.5	11.4	36.5	25.1	3.6	0.75
14.0	14.25	77.5	172.0	13.2	42.8	29.6	4.6	0.84
15.0	15.28	87.0	195.0	14.6	48.5	33.9	5.2	0.83
16.0	16.30	94.0	212.0	15.8	52.7	36.9	5.5	0.80

1"* SPACING ARRAY - 6 PLATELETS

(Bottom view)



(Not to scale)

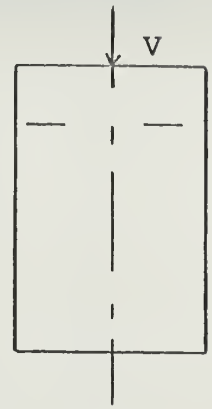
V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	3.0	0.5	1.0	0.5	0.0	0.00
3.0	3.06	2.5	7.5	0.8	2.2	1.4	0.5	1.32
4.0	4.08	5.0	13.5	1.3	3.6	2.3	0.4	0.60
5.0	5.10	7.5	21.0	1.6	5.5	3.9	0.8	0.76
6.0	6.12	11.0	30.5	2.2	7.8	5.6	1.3	0.86
7.0	7.13	21.0	44.0	3.9	11.2	7.3	1.2	0.59
8.0	8.15	27.0	59.0	4.8	15.0	10.2	2.0	0.75
9.0	9.16	32.0	73.5	5.6	18.5	12.9	2.6	0.77
10.0	10.18	39.0	93.0	6.7	23.4	16.7	3.7	0.89

1"* SPACING ARRAY - 6 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	52.0	114.0	9.0	28.5	19.5	3.9	0.77
12.0	12.20	60.0	134.0	10.2	33.5	23.3	4.7	0.78
13.0	13.22	70.5	155.5	12.0	38.7	26.7	5.2	0.74
14.0	14.25	81.0	181.0	13.6	45.0	31.4	6.4	0.78
15.0	15.28	90.0	205.5	15.2	51.2	36.0	7.3	0.77
16.0	16.30	97.5	225.0	16.4	56.0	39.6	8.2	0.79

1 1/4" SPACING ARRAY - 2 PLATELETS

(Bottom view)



(Not to scale)

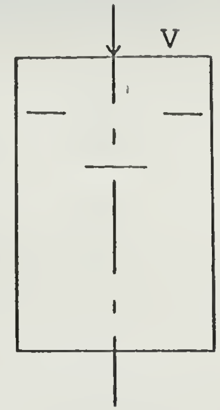
V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	$F_L - F_u$ (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	3.0	0.5	1.0	0.5	0.0	0.00
3.0	3.06	2.5	5.0	0.8	1.5	0.7	0.0	0.00
4.0	4.08	3.5	7.0	1.0	2.0	1.0	0.2	0.89
5.0	5.10	8.5	20.5	1.8	5.3	3.5	1.3	3.71
6.0	6.12	10.0	24.5	2.0	6.4	4.4	1.3	2.58
7.0	7.13	16.0	37.5	3.0	9.5	6.5	0.9	1.32
8.0	8.15	19.0	49.0	3.5	12.5	9.0	1.5	1.68
9.0	9.16	28.5	64.0	5.0	16.1	11.1	1.7	1.51
10.0	10.18	37.0	80.0	6.5	20.1	13.6	2.1	1.52

1 1/4" SPACING ARRAY - 2 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	53.0	100.0	9.0	25.0	16.0	1.8	1.07
12.0	12.20	62.5	117.5	10.7	29.4	18.7	2.4	1.21
13.0	13.22	75.0	139.0	12.7	34.7	22.0	2.9	1.24
14.0	14.25	89.0	165.0	15.0	41.2	26.2	3.1	1.04
15.0	15.28	99.0	187.5	16.6	46.7	30.1	3.9	1.25
16.0	16.30	107.5	204.5	18.0	51.8	33.2	3.7	1.07

1 1/4" SPACING ARRAY - 3 PLATELETS

(Bottom view)



(Not to scale)

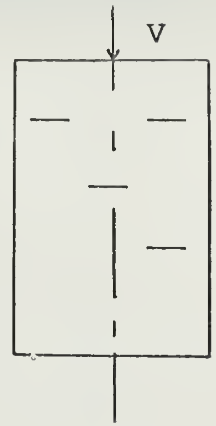
V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	3.0	0.5	1.0	0.5	0.0	0.00
3.0	3.06	2.5	5.0	0.8	1.5	0.7	0.0	0.00
4.0	4.08	4.0	11.0	1.0	3.0	2.0	1.2	3.58
5.0	5.10	9.0	22.5	1.9	5.7	3.8	1.6	3.06
6.0	6.12	11.0	29.0	2.2	7.5	5.3	2.2	2.92
7.0	7.13	17.0	40.5	3.2	10.3	7.1	1.5	1.47
8.0	8.15	23.5	53.5	4.2	13.5	9.3	1.8	1.35
9.0	9.16	29.0	68.0	5.1	17.1	12.0	2.6	1.54
10.0	10.18	37.5	84.0	6.5	21.1	14.6	3.1	1.49

1 1/4" SPACING ARRAY - 3 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	$F_L - F_u$ (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	53.0	105.5	9.0	26.4	17.4	3.2	1.27
12.0	12.20	63.0	123.0	10.7	30.7	20.0	3.7	1.24
13.0	13.22	76.0	145.5	12.9	36.3	23.4	4.3	1.22
14.0	14.25	90.0	171.0	15.2	42.6	27.4	4.3	1.05
15.0	15.28	100.0	194.0	16.7	48.3	31.6	5.4	1.15
16.0	16.30	108.5	214.0	18.1	53.3	35.2	5.7	1.10

1 1/4" SPACING ARRAY - 4 PLATELETS

(Bottom view)



(Not to scale)

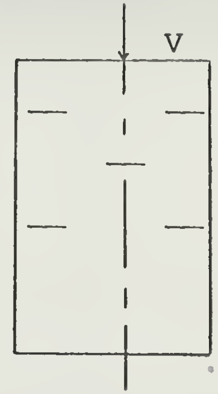
V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	3.0	0.5	1.0	0.5	0.0	0.00
3.0	3.06	2.5	5.0	0.8	1.5	0.7	0.0	0.00
4.0	4.08	5.0	11.0	1.2	3.0	1.8	1.0	2.23
5.0	5.10	7.5	16.0	1.6	4.2	2.6	0.4	0.57
6.0	6.12	13.0	30.0	2.5	7.0	4.5	1.4	1.40
7.0	7.13	17.5	41.0	3.2	10.5	7.3	1.7	1.25
8.0	8.15	25.0	56.0	4.5	14.1	9.6	2.1	1.18
9.0	9.16	31.0	72.0	5.5	18.1	12.6	3.2	1.42
10.0	10.18	41.0	87.5	7.1	22.0	14.9	4.4	1.40

1 1/4" SPACING ARRAY - 4 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	$F_L - F_u$ (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	51.0	106.5	8.7	26.7	18.0	3.8	1.13
12.0	12.20	64.5	127.0	11.0	31.7	20.7	4.4	1.10
13.0	13.22	79.0	152.0	13.4	38.0	24.6	5.5	1.17
14.0	14.25	95.0	180.0	16.0	44.8	28.8	5.7	1.05
15.0	15.28	105.0	204.0	17.6	50.8	33.2	7.0	1.12
16.0	16.30	113.5	222.5	19.0	55.7	36.7	7.2	1.04

1 1/4" SPACING ARRAY - 5 PLATELETS

(Bottom view)



(Not to scale)

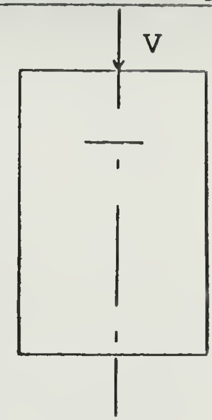
V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	3.0	0.5	1.0	0.5	0.0	0.00
3.0	3.06	2.5	6.0	0.8	1.7	0.9	0.2	0.64
4.0	4.08	5.0	11.0	1.2	3.0	1.8	1.0	1.79
5.0	5.10	7.5	15.5	1.6	4.1	2.5	0.3	0.34
6.0	6.12	12.0	27.0	2.4	7.0	4.6	1.5	1.77
7.0	7.13	13.5	39.0	2.6	10.0	7.4	1.8	1.05
8.0	8.15	19.5	53.0	3.5	13.4	9.9	2.4	1.08
9.0	9.16	27.0	68.0	4.8	17.1	12.3	2.9	1.03
10.0	10.18	38.0	88.0	6.6	22.0	15.4	3.9	1.12

1 1/4" SPACING ARRAY - 5 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	50.0	109.0	8.6	27.3	18.7	4.5	1.07
12.0	12.20	63.5	132.0	10.8	33.0	22.2	5.9	1.18
13.0	13.22	75.0	155.0	12.7	38.6	25.9	6.8	1.16
14.0	14.25	92.5	186.0	15.6	46.3	30.7	7.6	1.12
15.0	15.28	104.0	210.0	17.5	52.2	34.7	8.5	1.09
16.0	16.30	114.5	233.0	19.5	58.2	39.0	9.5	1.10

NO SPACING ARRAY - 2 PLATELETS

(Bottom view)



(Not to scale)

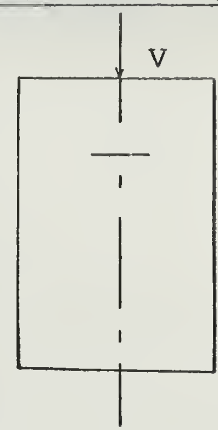
V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	3.0	0.5	1.0	0.5	0.0	0.00
3.0	3.06	2.5	6.0	0.8	1.7	0.9	0.1	0.79
4.0	4.08	4.0	11.0	1.1	3.0	1.9	0.0	0.00
5.0	5.10	7.0	18.0	1.5	4.7	3.2	0.1	0.29
6.0	6.12	10.5	25.5	2.2	6.6	4.4	0.1	0.20
7.0	7.13	13.5	34.0	2.6	8.7	6.1	0.5	0.73
8.0	8.15	18.5	45.5	3.4	11.5	8.1	0.6	0.67
9.0	9.16	23.5	59.0	4.3	14.9	10.6	0.8	0.71
10.0	10.18	33.5	77.5	5.8	19.5	13.7	1.5	1.08

NO SPACING ARRAY - 2 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	40.0	94.0	7.0	23.5	16.5	1.5	0.89
12.0	12.20	40.0	106.5	7.0	26.7	19.7	1.9	0.95
13.0	13.22	51.0	128.0	8.8	32.0	23.2	2.2	0.94
14.0	14.25	68.5	152.5	11.6	37.9	26.3	1.8	0.66
15.0	15.28	83.5	178.0	14.1	44.3	30.2	2.7	0.86
16.0	16.30	95.0	198.0	16.0	49.3	33.3	3.3	0.92

NO SPACING ARRAY - 3 PLATELETS

(Bottom view)



(Not to scale)

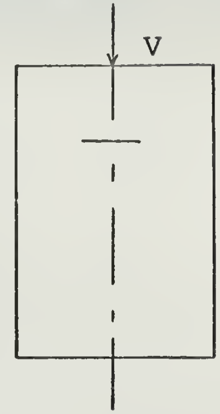
V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	3.0	0.5	1.0	0.5	0.0	0.00
3.0	3.06	2.5	6.0	0.8	1.7	0.9	0.1	0.53
4.0	4.08	5.0	12.0	1.2	3.3	2.1	0.2	0.60
5.0	5.10	7.5	18.5	1.6	4.8	3.2	0.1	0.19
6.0	6.12	11.5	26.5	2.3	6.8	4.5	0.2	0.27
7.0	7.13	14.5	35.5	2.7	9.1	6.4	0.8	0.78
8.0	8.15	19.0	48.0	3.5	12.2	8.7	1.2	0.90
9.0	9.16	24.0	61.0	4.3	15.4	11.1	1.3	0.77
10.0	10.18	35.5	80.5	6.2	20.2	14.0	1.8	0.87

NO SPACING ARRAY - 3 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	40.0	97.0	7.0	24.4	17.4	2.4	0.95
12.0	12.20	40.0	110.0	7.0	27.5	20.5	2.7	0.90
13.0	13.22	51.0	131.0	8.7	32.7	24.0	3.0	0.85
14.0	14.25	69.0	158.0	11.7	39.4	27.7	3.2	0.78
15.0	15.28	84.5	184.0	14.3	45.8	31.5	4.0	0.85
16.0	16.30	96.0	204.0	16.1	50.8	34.7	4.7	0.88

NO SPACING ARRAY - 5 PLATELETS

(Bottom view)



(Not to scale)

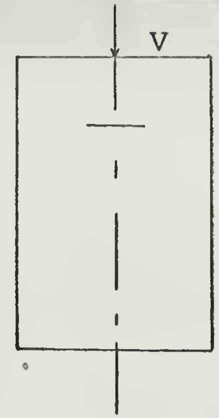
V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	3.0	0.5	1.0	0.5	0.0	0.00
3.0	3.06	2.5	7.5	0.8	2.1	1.3	0.5	1.59
4.0	4.08	5.0	13.0	1.2	3.5	2.3	0.4	0.71
5.0	5.10	7.5	19.5	1.6	5.1	3.5	0.4	0.46
6.0	6.12	11.0	28.0	2.2	7.2	5.0	0.7	0.56
7.0	7.13	13.5	38.0	2.6	9.7	7.1	1.5	0.88
8.0	8.15	17.5	51.0	3.3	12.9	9.6	2.1	0.94
9.0	9.16	23.0	65.5	4.1	16.5	12.4	2.6	0.92
10.0	10.18	34.0	85.0	6.0	21.4	15.4	3.2	0.92

NO SPACING ARRAY - 5 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	$F_L - F_u$ (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	37.5	102.0	6.5	25.5	19.0	4.0	0.95
12.0	12.20	45.0	121.0	7.7	30.2	22.5	4.7	0.94
13.0	13.22	56.0	142.5	9.5	35.6	26.1	5.1	0.87
14.0	14.25	70.0	168.0	11.9	41.8	29.9	5.4	0.79
15.0	15.28	87.0	199.0	14.6	49.5	34.9	7.4	0.95
16.0	16.30	99.0	221.0	16.6	55.0	38.4	8.4	0.94

NO SPACING ARRAY - 7 PLATELETS

(Bottom view)



(Not to scale)

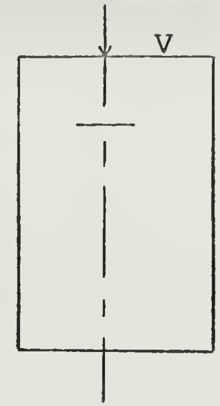
V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	4.0	0.5	1.2	0.7	0.2	1.02
3.0	3.06	2.5	7.5	0.8	2.1	1.3	0.5	1.14
4.0	4.08	3.4	14.0	1.0	3.7	2.7	0.8	1.02
5.0	5.10	5.0	21.0	1.2	5.5	4.3	1.2	0.98
6.0	6.12	9.5	31.0	1.9	8.0	6.1	1.8	1.01
7.0	7.13	12.5	41.0	2.4	10.5	8.1	2.5	1.05
8.0	8.15	17.5	56.0	3.2	14.1	10.9	3.4	1.09
9.0	9.16	22.5	70.0	4.1	17.6	13.5	3.7	0.94
10.0	10.18	34.0	94.0	6.0	23.5	17.5	5.3	1.09

NO SPACING ARRAY - 7 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	$F_L - F_u$ (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	38.5	112.0	6.7	28.0	21.3	6.3	1.07
12.0	12.20	42.0	128.0	7.3	32.0	24.7	6.9	0.99
13.0	13.22	53.0	153.0	9.0	38.2	29.2	8.2	1.00
14.0	14.25	67.5	182.0	11.5	45.3	33.8	9.3	0.98
15.0	15.28	83.5	213.5	14.1	53.2	39.1	11.6	1.06
16.0	16.30	94.0	234.0	15.8	58.2	42.4	12.4	1.00

NO SPACING ARRAY - 9 PLATELETS

(Bottom view)



(Not to scale)

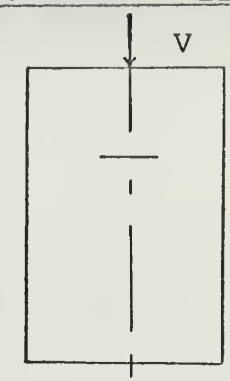
V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	$F_L - F_u$ (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	4.0	0.5	1.2	0.7	0.2	0.80
3.0	3.06	2.5	8.0	0.8	2.3	1.5	0.7	1.24
4.0	4.08	3.5	14.5	1.0	3.8	2.8	0.9	0.89
5.0	5.10	6.0	23.0	1.4	6.0	4.6	1.5	0.95
6.0	6.12	9.0	33.0	1.9	8.5	6.6	2.3	1.02
7.0	7.13	12.0	44.5	2.4	11.3	8.9	3.3	1.07
8.0	8.15	16.0	59.0	3.0	14.9	11.9	4.4	1.09
9.0	9.16	21.0	77.0	3.8	19.4	15.6	5.8	1.13
10.0	10.18	35.0	102.0	6.2	25.5	19.3	7.1	1.13

NO SPACING ARRAY - 9 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	32.5	116.5	5.7	29.2	23.5	8.5	1.12
12.0	12.20	39.5	139.5	6.8	34.8	28.0	10.2	1.13
13.0	13.22	50.0	165.0	8.6	41.1	32.5	11.5	1.09
14.0	14.25	63.5	195.0	10.8	48.5	37.7	13.2	1.07
15.0	15.28	78.0	224.0	13.2	55.7	42.5	15.0	1.06
16.0	16.30	89.0	253.0	15.0	62.9	47.9	17.9	1.01

NO SPACING ARRAY - 11 PLATELETS

(Bottom view)



(Not to scale)

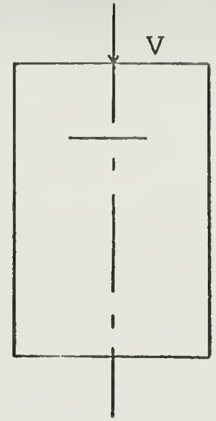
V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	4.0	0.5	1.2	0.7	0.2	0.65
3.0	3.06	2.5	8.5	0.8	2.3	1.5	0.7	1.01
4.0	4.08	4.0	15.0	1.1	4.0	2.9	1.0	0.81
5.0	5.10	7.0	24.0	1.5	6.2	4.7	1.6	0.83
6.0	6.12	10.0	35.0	2.0	9.0	7.0	2.7	0.97
7.0	7.13	12.5	46.0	2.4	11.7	9.3	3.7	0.98
8.0	8.15	16.5	63.5	3.1	16.0	12.9	5.4	1.10
9.0	9.16	21.0	82.0	3.8	20.6	16.8	7.0	1.13
10.0	10.18	35.0	106.0	6.2	26.5	20.3	8.1	1.06

NO SPACING ARRAY - 11 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	35.0	125.5	6.2	31.3	25.1	10.1	1.09
12.0	12.20	41.0	147.0	7.1	36.7	29.6	11.8	1.07
13.0	13.22	50.0	175.0	8.6	43.6	35.0	14.0	1.08
14.0	14.25	63.0	207.0	10.7	51.5	40.8	16.3	1.09
15.0	15.28	78.0	240.0	13.2	59.7	46.5	19.0	1.10
16.0	16.30	88.0	267.0	14.8	66.4	51.6	21.6	1.10

NO SPACING ARRAY - 13 PLATELETS

(Bottom view)



(Not to scale)

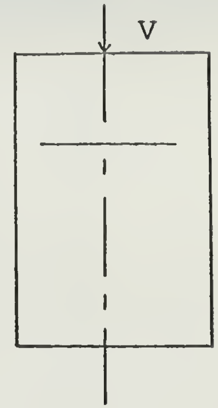
V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	4.0	0.5	1.2	0.7	0.2	0.55
3.0	3.06	2.5	10.0	0.8	2.7	1.9	1.1	1.34
4.0	4.08	4.0	16.5	1.1	4.3	3.2	1.3	0.89
5.0	5.10	7.0	25.0	1.5	6.5	5.0	1.9	0.84
6.0	6.12	9.5	36.5	2.0	9.3	7.3	3.0	0.92
7.0	7.13	13.0	49.5	2.5	12.6	10.1	4.5	1.02
8.0	8.15	16.0	67.0	3.0	16.9	13.9	6.4	1.10
9.0	9.16	21.0	87.0	4.8	21.8	17.0	7.2	0.98
10.0	10.18	38.5	115.0	6.7	28.7	22.0	9.8	1.09

NO SPACING ARRAY - 13 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	35.0	130.0	6.1	32.5	26.4	11.4	1.04
12.0	12.20	41.0	156.0	7.1	38.9	31.8	14.0	1.08
13.0	13.22	48.0	184.0	8.3	45.8	37.5	16.5	1.08
14.0	14.25	60.0	216.0	10.2	53.7	43.5	19.0	1.07
15.0	15.28	73.0	252.0	12.4	62.7	50.3	22.8	1.12
16.0	16.30	84.0	281.0	14.2	69.8	55.6	25.6	1.10

NO SPACING ARRAY - 15 PLATELETS

(Bottom view)



(Not to scale)

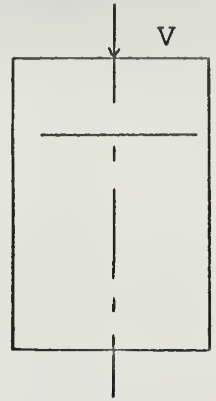
V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	$F_L - F_u$ (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	4.0	0.5	1.2	0.7	0.2	0.48
3.0	3.06	2.5	10.0	0.8	2.7	1.9	1.1	1.17
4.0	4.08	4.0	16.5	1.1	4.3	3.2	1.3	0.78
5.0	5.10	7.5	26.5	1.6	6.8	5.2	2.1	0.80
6.0	6.12	10.0	39.0	2.0	10.0	8.0	3.7	0.98
7.0	7.13	13.0	52.5	2.5	13.2	10.7	5.1	1.00
8.0	8.15	16.0	70.0	3.0	17.6	14.6	7.1	1.06
9.0	9.16	21.0	90.0	3.8	22.5	18.7	8.9	1.05
10.0	10.18	36.0	121.0	6.3	30.2	23.9	11.7	1.13

NO SPACING ARRAY - 15 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	36.0	140.0	6.3	35.0	28.7	13.7	1.08
12.0	12.20	42.0	169.0	7.2	42.1	34.9	17.1	1.14
13.0	13.22	48.0	196.0	8.3	48.8	40.5	19.5	1.11
14.0	14.25	60.0	232.0	10.2	57.7	47.5	23.0	1.12
15.0	15.28	71.0	268.0	12.0	66.6	54.6	27.1	1.16
16.0	16.30	82.0	298.0	13.8	74.0	60.2	30.2	1.13

NO SPACING ARRAY - 17 PLATELETS

(Bottom view)



(Not to Scale)

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
2.0	2.04	1.0	4.0	0.5	1.2	0.7	0.2	0.42
3.0	3.06	2.5	10.5	0.8	2.8	2.0	1.2	1.12
4.0	4.08	5.0	19.0	1.2	5.0	3.8	1.9	1.00
5.0	5.10	6.5	29.5	1.5	7.6	6.1	3.0	1.01
6.0	6.12	9.5	43.0	2.0	11.0	9.0	4.7	1.10
7.0	7.13	12.5	57.5	2.4	14.5	12.1	6.5	1.12
8.0	8.15	15.0	77.5	2.8	19.5	16.7	9.2	1.21
9.0	9.16	19.0	97.0	3.5	24.3	20.8	11.0	1.15
10.0	10.18	24.0	122.0	4.3	30.5	26.2	14.0	1.19

NO SPACING ARRAY - 17 PLATELETS

V_p (kts)	V_m (ft/sec)	D_u (counts)	D_L (counts)	F_u (lbf)	F_L (lbf)	F_L-F_u (lbf)	DRAG CORR. (lbf)	C_D
11.0	11.20	29.0	147.0	5.6	36.7	31.1	16.1	1.12
12.0	12.20	39.0	177.5	6.8	44.2	37.4	19.6	1.15
13.0	13.22	50.0	209.0	8.6	52.0	43.4	22.4	1.12
14.0	14.25	70.0	253.0	11.9	62.9	51.0	26.5	1.14
15.0	15.28	75.0	288.0	12.7	71.6	58.9	31.4	1.18
16.0	16.30	89.0	318.0	15.0	79.0	64.0	34.0	1.12

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Slowing down of super-
tankers by use of semi-
tandem keel mounted
plates.